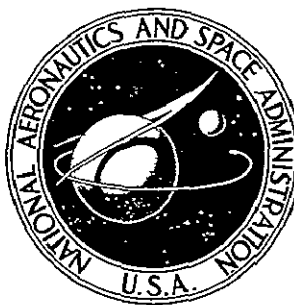


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SUPERSONIC AERODYNAMIC CHARACTERISTICS
OF A ROCKET-VEHICLE MODEL WITH
LOW-ASPECT-RATIO WING AND TAIL SURFACES

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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the static aerodynamic characteristics of a rocket-vehicle model with low-aspect-ratio cruciform wing and tail surfaces at Mach numbers from 1.50 to 4.64.

The results indicate that the model with the wings in the aft position provided less variation in the center-of-pressure location with Mach number than the model with the wings in the forward position. For both wing positions, however, the model exhibited nonlinear pitching-moment characteristics in the lower Mach number and angle-of-attack ranges. Little or no induced roll or yaw was indicated over the ranges of angle of attack and Mach number in this investigation.

INTRODUCTION

A rocket vehicle with low-aspect-ratio wing and tail surfaces is currently under development by the U.S. Army Missile Command. The vehicle design concept was to provide a relatively constant static margin over the supersonic Mach number range by means of center-of-pressure variation offsetting center-of-gravity movement due to fuel consumption.

The program development has proceeded to the stage where experimental verification of the aerodynamic characteristics of the rocket vehicle is required. Accordingly, the National Aeronautics and Space Administration has conducted a series of tests to determine the static aerodynamic characteristics of a model of such a vehicle at Mach numbers from 1.50 to 4.64. The model had a fineness ratio of about 13, small rectangular cruciform wings, and a flared afterbody with inline low-aspect-ratio rectangular fins.

The tests, for which results are presented herein, were performed in the Langley Unitary Plan wind tunnel through an angle-of-attack range from -7° to 7° at a constant Reynolds number of 9.84×10^6 per meter (3×10^6 per foot).

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements were made in U.S. Customary Units. Force and moment coefficient data are referenced to the body-axis system. Moment data are referred to a point 52.45 cm (20.65 inches) aft of the model nose apex.

b	reference length (nominal body diameter), 7.62 cm (3.00 inches)
C_A	axial-force coefficient, $\frac{\text{Axial force}}{qS}$
$C_{A,b}$	base-axial-force coefficient, $\frac{\text{Base axial force}}{qS}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSb}$
C_{m_α}	slope of pitching-moment-coefficient curve measured about $\alpha = 0^\circ$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qS}$
C_{N_α}	slope of normal-force-coefficient curve measured about $\alpha = 0^\circ$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
M	free-stream Mach number
q	free-stream dynamic pressure
S	reference area, 0.00456 m ² (0.049087 ft ²)
x_{cp}/l	center-of-pressure location, percent body length (from nose), $\frac{C_{m_\alpha}}{C_{N_\alpha}}$
α	angle of attack, deg
ϕ	model roll angle, with $\phi = 0^\circ$ referring to fins in a horizontal-vertical orientation (positive clockwise when looking upstream), deg
ψ	wing rotation with respect to fins (positive clockwise when looking upstream), deg

Model nomenclature:

B	body (including nose, centerbody, and flared afterbody)
C _{X₁}	wings in forward position
C _{X₂}	wings in aft position
F	fins

APPARATUS AND TESTS

Model

A drawing of the model is presented in figure 1, and a photograph of the model is shown in figure 2. The body has a fineness ratio (ratio of length to reference diameter) of about 13. The model includes an ogive nose with a ratio of length to maximum diameter of 3, a cylindrical centerbody, and a 3.47° flared afterbody. Small rectangular cruciform wings were located at one of two longitudinal positions on the body, and inline fins were located on the aft portion of the flare. Provision was made to rotate the wings 5° counterclockwise (looking upstream) with respect to the fins. Unless otherwise noted, wings and fins are positioned inline.

Test Conditions

Tests were performed through an angle-of-attack range from about -7° to 7° at Mach numbers from 1.50 to 4.64. Test conditions are shown in the following table:

Mach number	Stagnation pressure		Stagnation temperature	
	N/m ²	lb/ft ²	°K	°F
1.50	79 768.51	1666	338.71	150
1.90	91 307.65	1907	338.71	150
2.36	113 428.33	2369	338.71	150
2.87	147 662.72	3084	338.71	150
3.85	262 814.74	5489	352.59	175
4.64	380 552.29	7948	352.59	175

The dewpoint temperature was maintained below 238.71° K (-30° F) in order to assure negligible condensation effects. All tests were performed with transition strips

of No. 40 carborundum grain affixed 3.05 cm (1.2 inches) aft of the nose apex and 1.02 cm (0.4 inch) aft of the leading edge on the wing and tail surfaces.

Measurements and Corrections

Forces and moments on the model were measured by means of a six-component strain-gage balance housed within the model and supported by a sting, which in turn was rigidly fastened to the tunnel support system. Balance-chamber pressure was measured by means of a single static orifice in the vicinity of the balance.

Angles of attack have been corrected for tunnel-airflow misalignment and deflection of the sting-balance combination due to aerodynamic loads. Axial-force data have been adjusted to a condition of free-stream static pressure acting over the entire base of the model by using measured balance-chamber pressure. Typical base-axial-force values are presented in figure 3.

RESULTS AND DISCUSSION

The effects of fins and of wings in the forward position (C_{X_1}) on the longitudinal characteristics of the model are shown in figures 4 and 5 for model roll angles (ϕ) of 0° and 45° , respectively. Throughout the Mach number range the data for all configurations indicate an increase in the slope of the normal-force-coefficient curve with increase in angle of attack. Adding the wings or fins generally provides about the same increase in normal-force coefficient (over the values obtained for the body alone). At low Mach numbers with both sets of surfaces on the model ($BC_{X_1}F$), there is generally only a small increase in C_N over the values obtained for either set of surfaces alone at the lower angles of attack; thus an adverse interference effect of the wings on the fins is indicated. At the higher Mach numbers and generally at the higher test angles of attack, this effect of the wings on the fins becomes smaller.

The body alone exhibits relatively linear pitching-moment characteristics at the lower Mach numbers; however, these characteristics become somewhat nonlinear at the higher Mach numbers (see figs. 4 and 5). Addition of the wings, while decreasing the stability level, has little effect on the linearity of the pitching-moment data. Addition of the fins to the body alone provides a significant stabilizing moment and leads to slightly nonlinear pitching-moment-coefficient curves over the Mach number range. The pitching-moment characteristics for the complete configuration ($BC_{X_1}F$) are relatively nonlinear, particularly in the lower Mach number range. In addition, at the lower angles of attack in the lower Mach number range, the fins on the complete model are relatively ineffective in producing pitching moments, presumably because of the wing interference effects. At the higher angles of attack the fins become effective as they move away from the influence

of the wings, and at the higher Mach numbers the fins are effective throughout the test angle-of-attack range.

The data in figures 4 and 5 also indicate that the increment in axial force due to the wings is noticeably larger than that due to the fins.

Other than providing a substantial increase in the stability level, positioning the wings in the aft location (BCX_2 , fins off) has little effect on the longitudinal characteristics of the model (figs. 6 and 7). Figures 8 and 9 indicate that the effects of wing position with the fins on are similar to those shown in figures 6 and 7 for the fins off. The data in figures 8 and 9 also show that a wing rotation of -5° (with respect to fin orientation) has little effect on the longitudinal characteristics of the model.

Figure 10 shows the variation in center-of-pressure location with Mach number for the model with various component combinations. It should be noted that exact determination of the center-of-pressure locations at the lower Mach numbers is difficult because of the nonlinear nature of the pitch data; however, the general trends are believed to be valid. The results indicate that the model with the wings in the aft position (BCX_2F) provides less variation in the center-of-pressure location than the model with the wings in the forward position (BCX_1F) over the test Mach number range. There is little or no forward movement of center of pressure with increase in Mach number for the wings in either position. For both wing positions, of course, the center of gravity must be located forward of the indicated center-of-pressure locations in order to achieve a stable configuration.

Figure 11 indicates little or no induced roll or yaw for any of the configurations over the angle-of-attack and Mach number ranges of these tests.

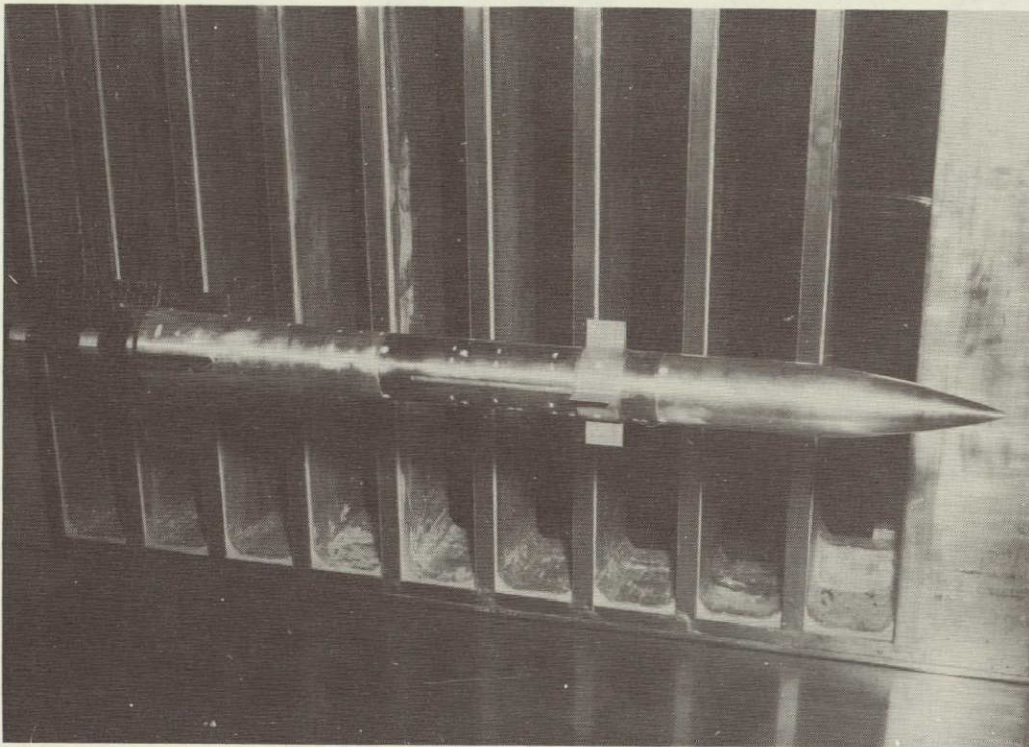
CONCLUDING REMARKS

An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the static aerodynamic characteristics of a rocket-vehicle model with low-aspect-ratio cruciform wing and tail surfaces at Mach numbers from 1.50 to 4.64.

The results indicate that the model with the wings in the aft position provided less variation in the center-of-pressure location than the model with the wings in the forward position over the test Mach number range. For both wing positions, however, the model exhibited nonlinear pitching-moment characteristics in the lower Mach number and angle-of-attack ranges. Little or no induced roll or yaw was indicated over the ranges of angle of attack and Mach number in this investigation.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 11, 1971.

Figure 1.- Drawing of model. (Unless otherwise noted, dimensions are given in inches and parenthetically in cm.)



L-69-7175

Figure 2.- Photograph of model.

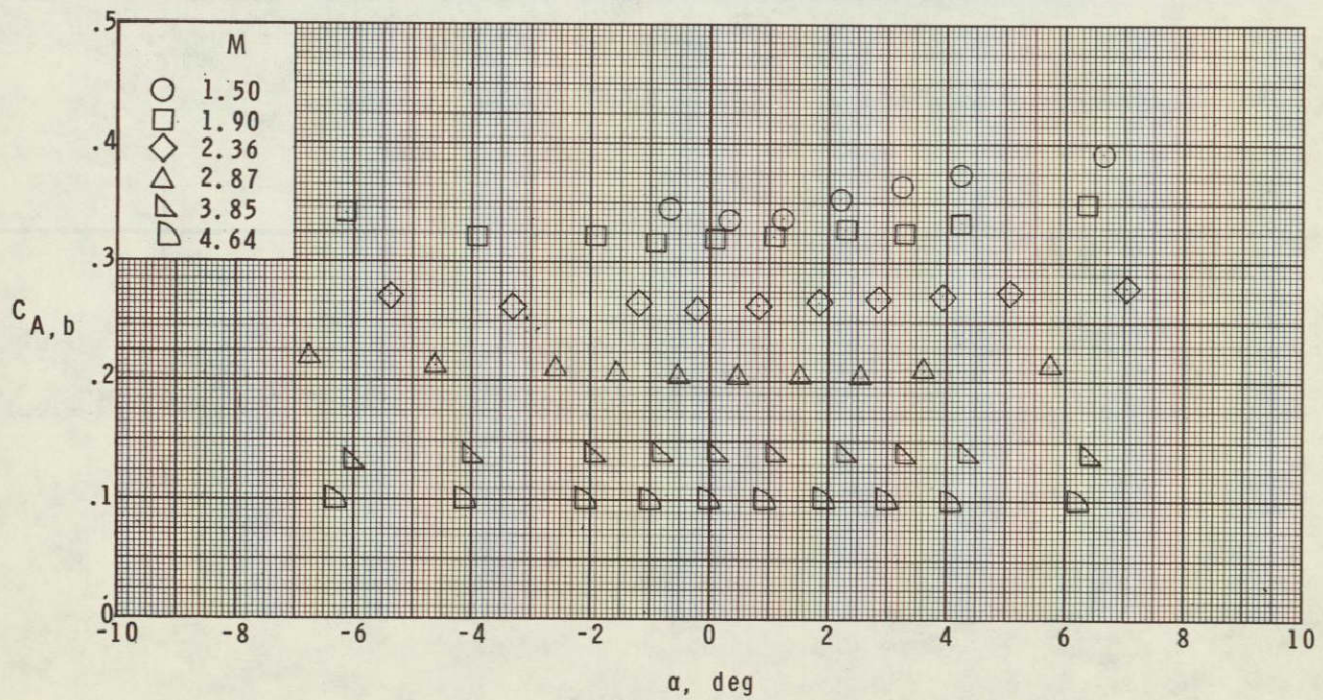
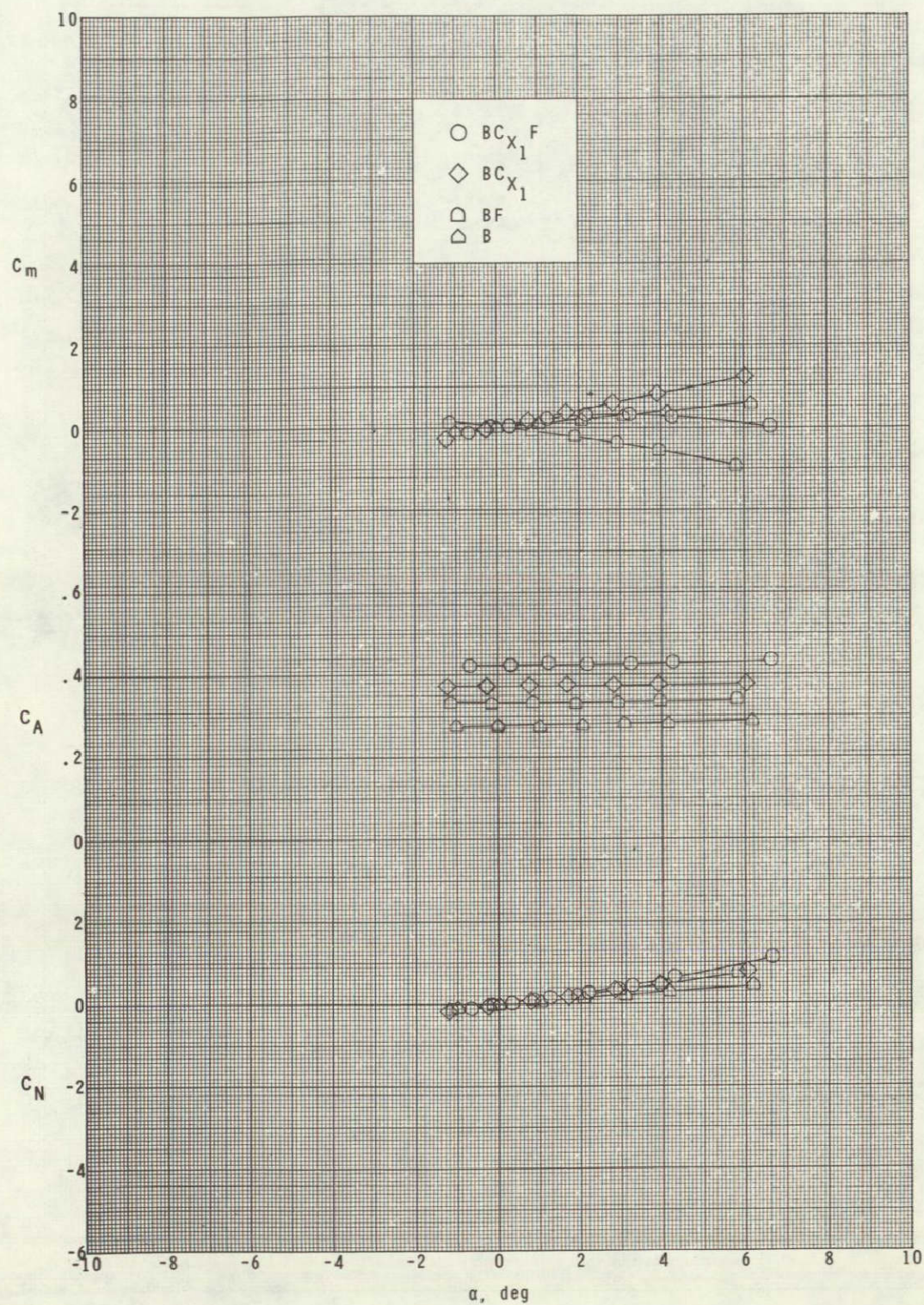
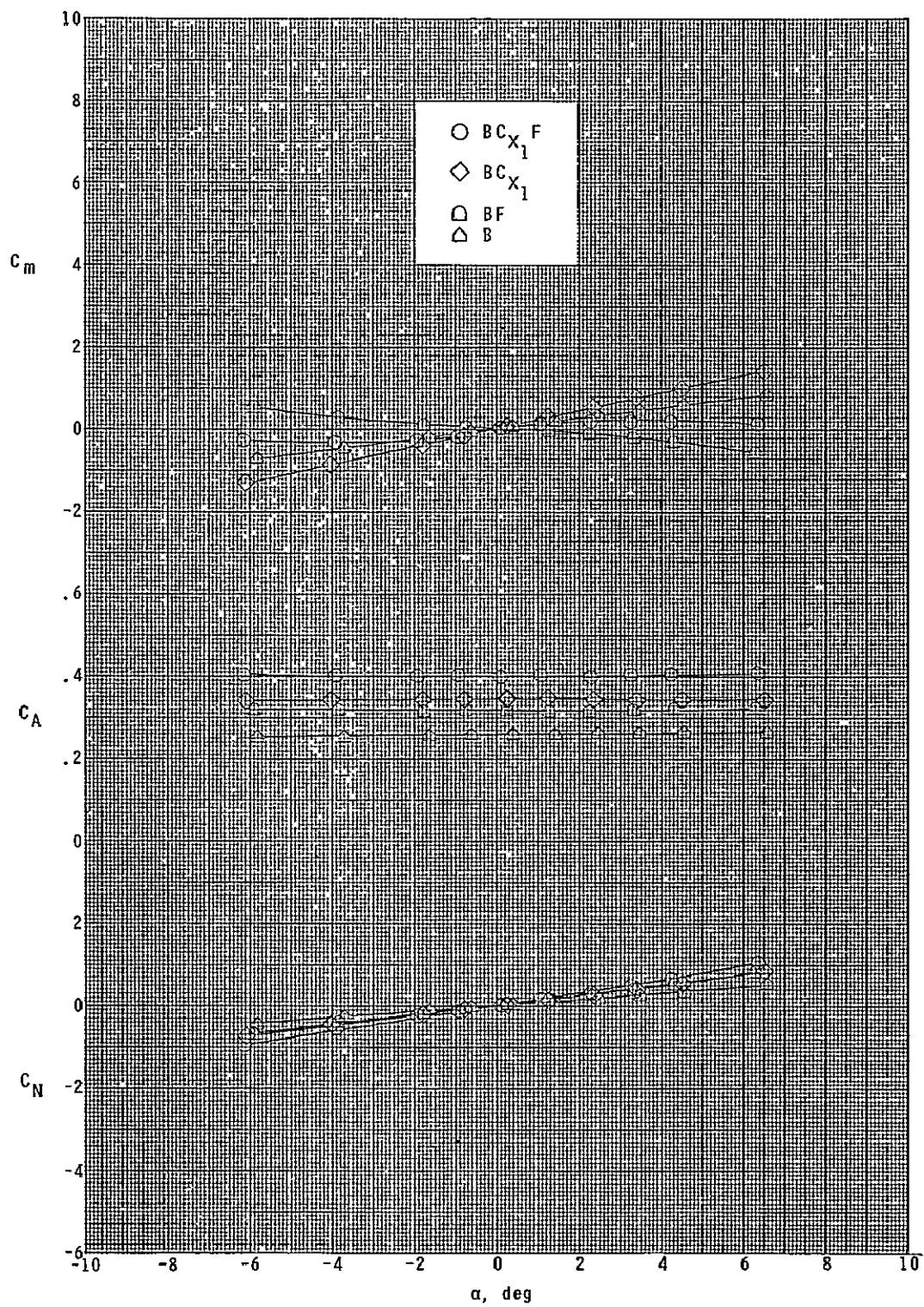


Figure 3.- Typical variation of base-axial-force coefficient with angle of attack.



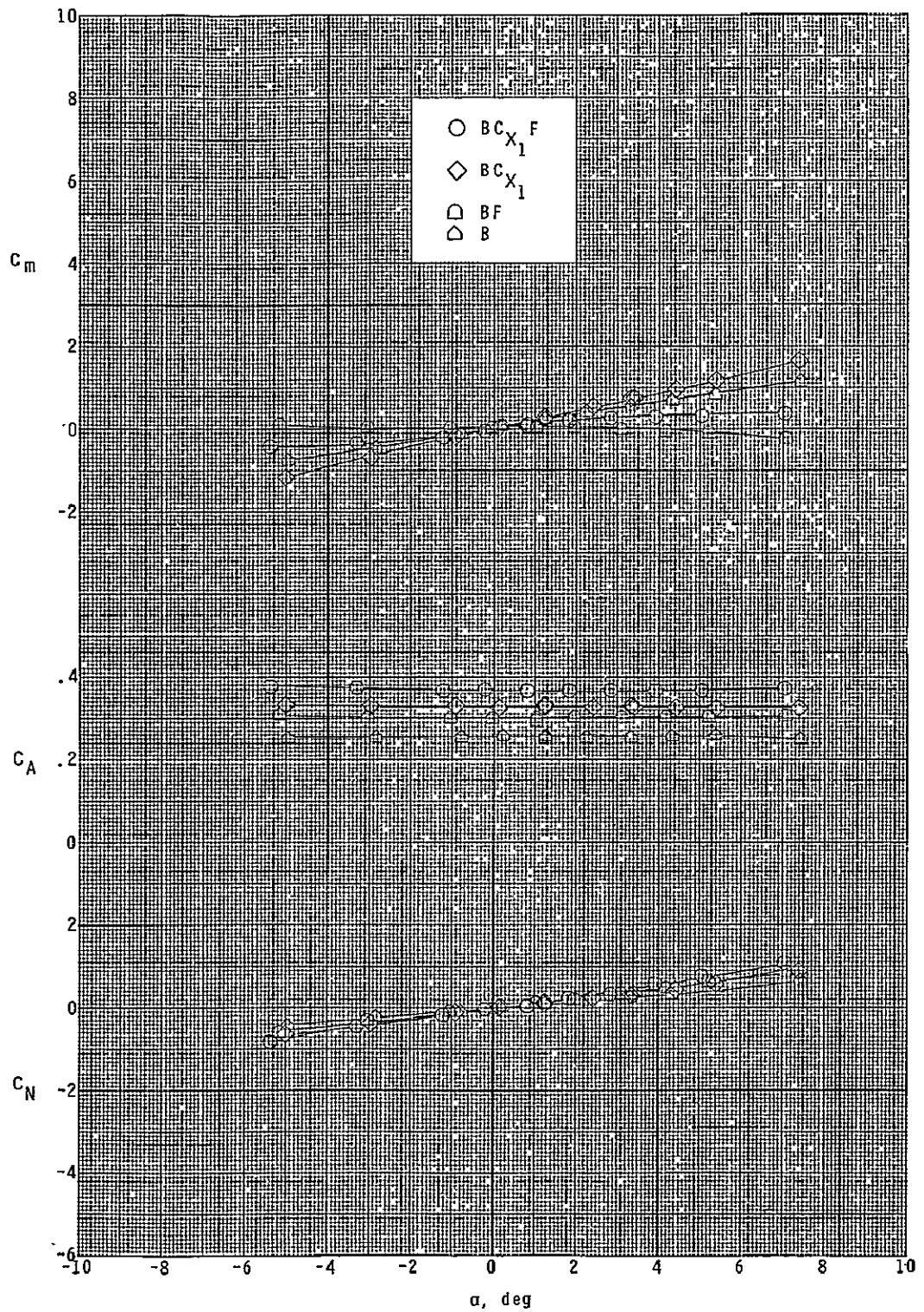
(a) $M = 1.50$.

Figure 4.- Effect of model components on longitudinal characteristics. $\phi = 0^\circ$.



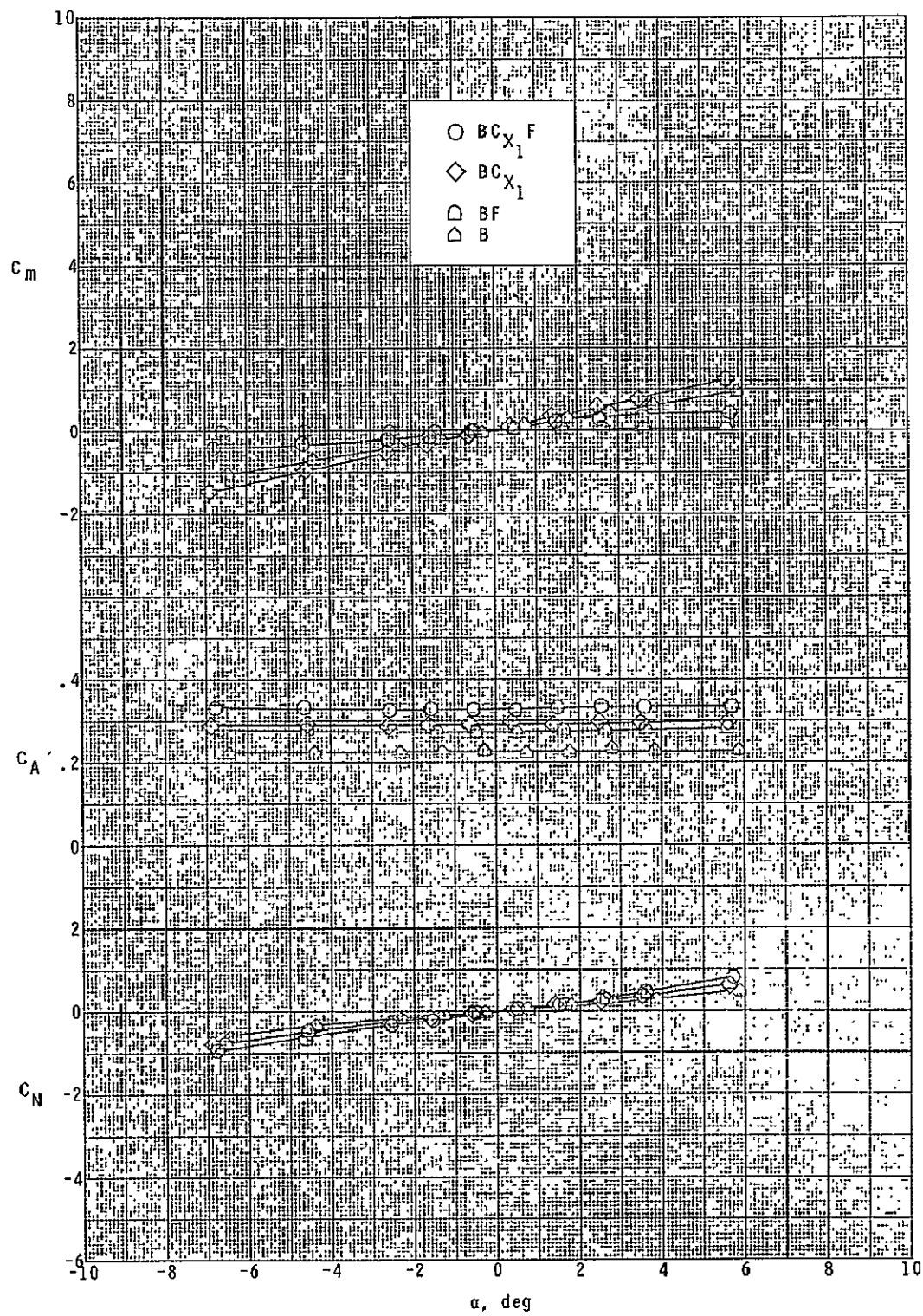
(b) $M = 1.90$.

Figure 4.- Continued.



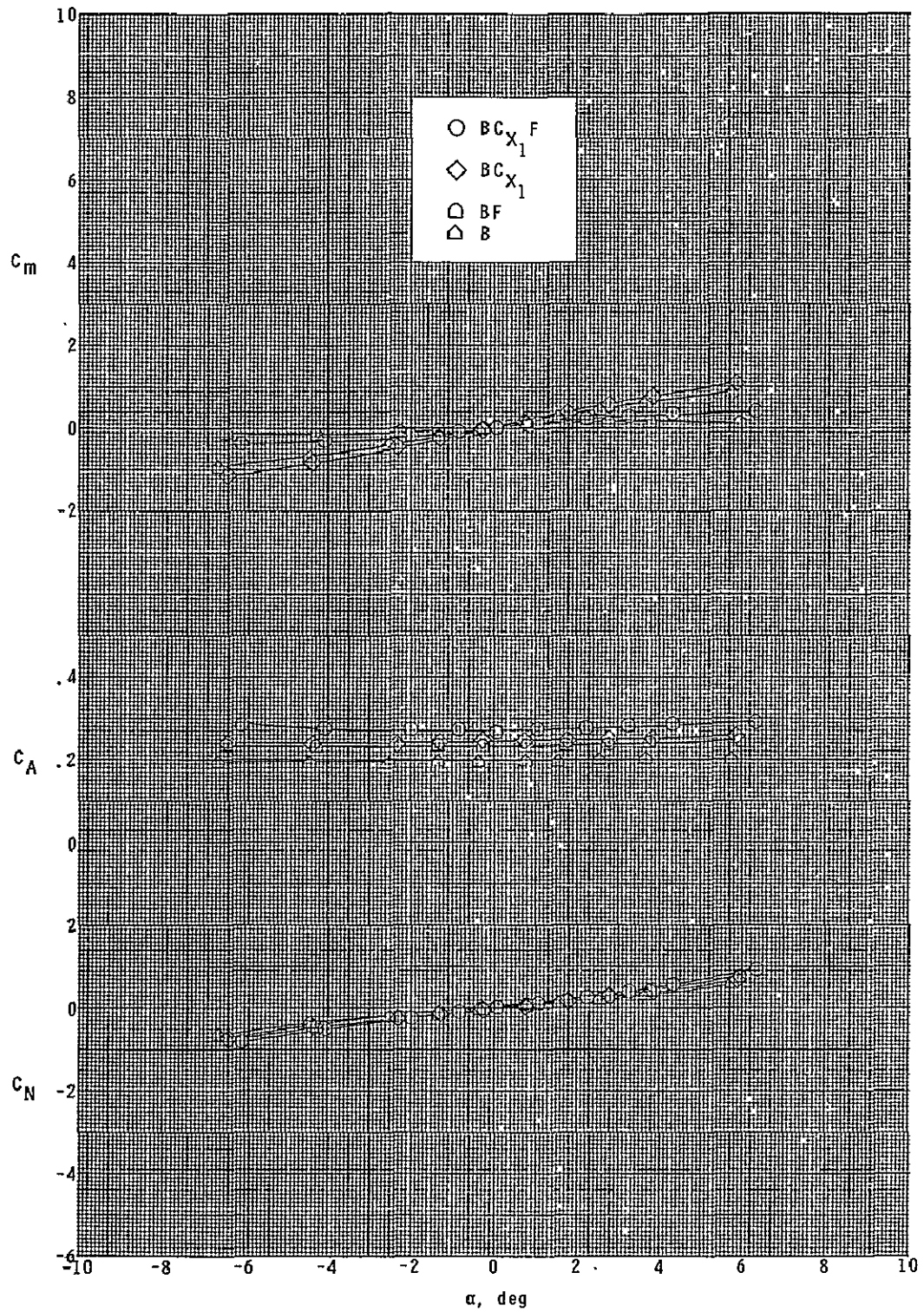
(c) $M = 2.36$.

Figure 4.- Continued.



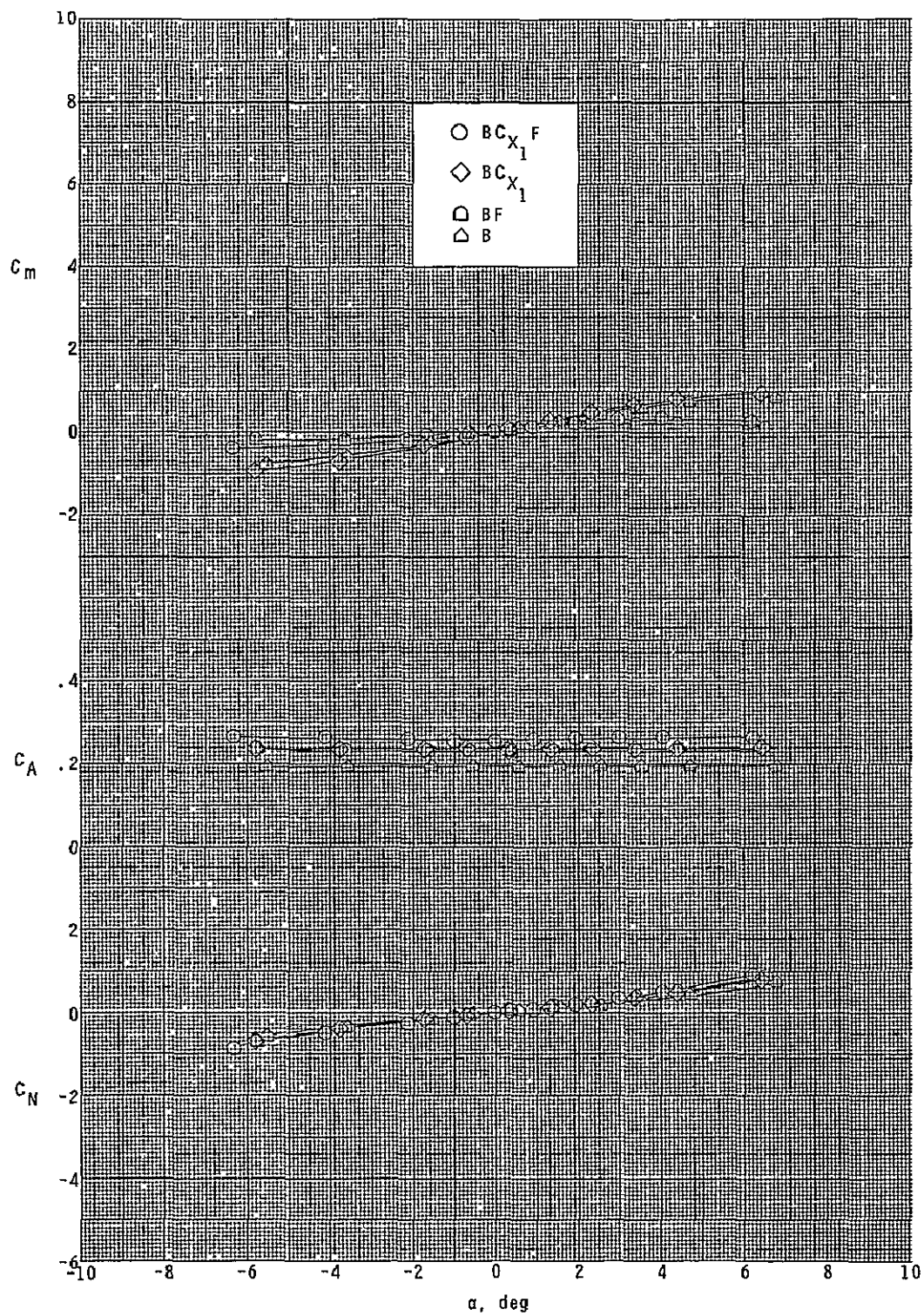
(d) $M = 2.87$.

Figure 4.- Continued.



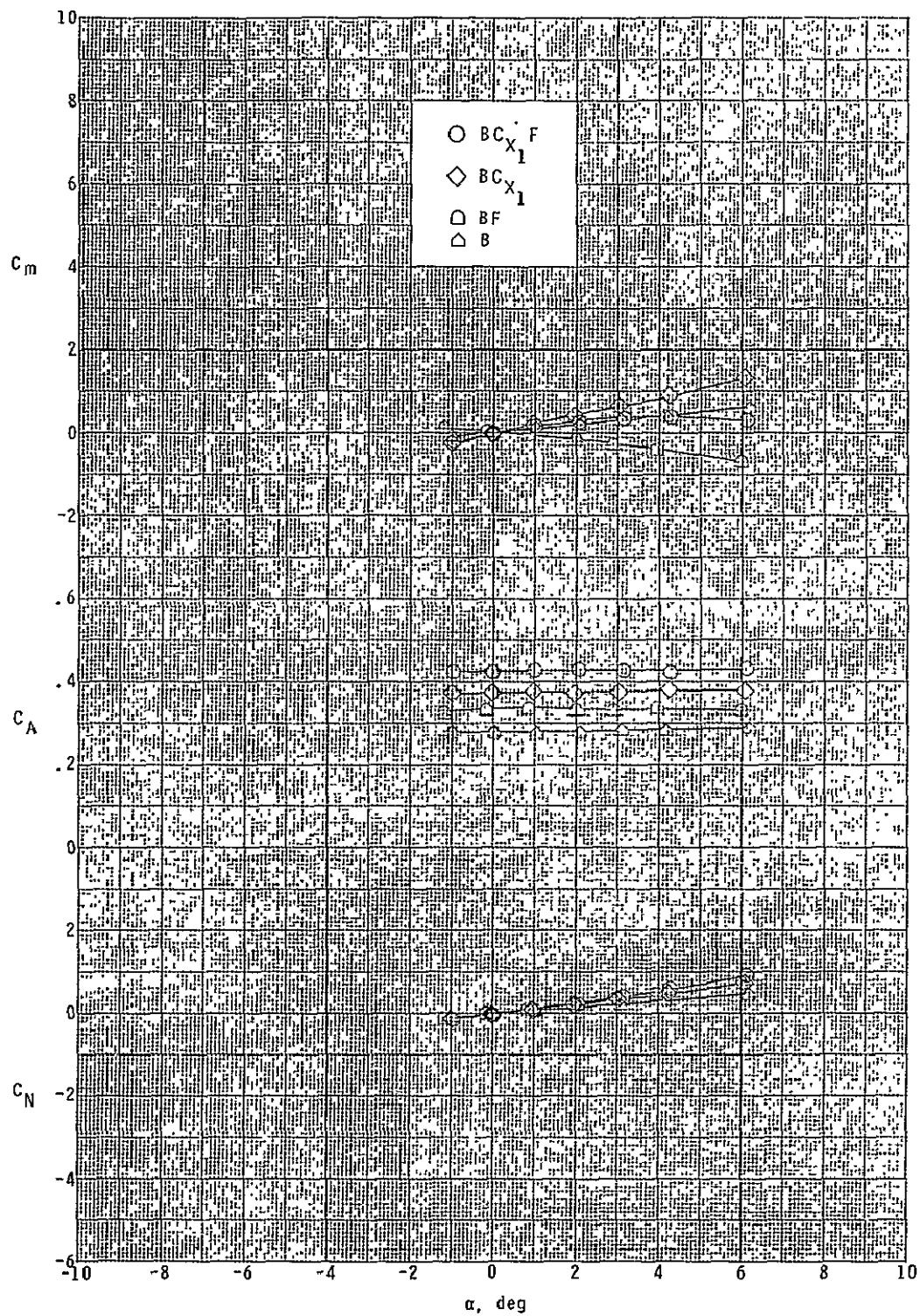
(e) $M = 3.85$.

Figure 4. - Continued.



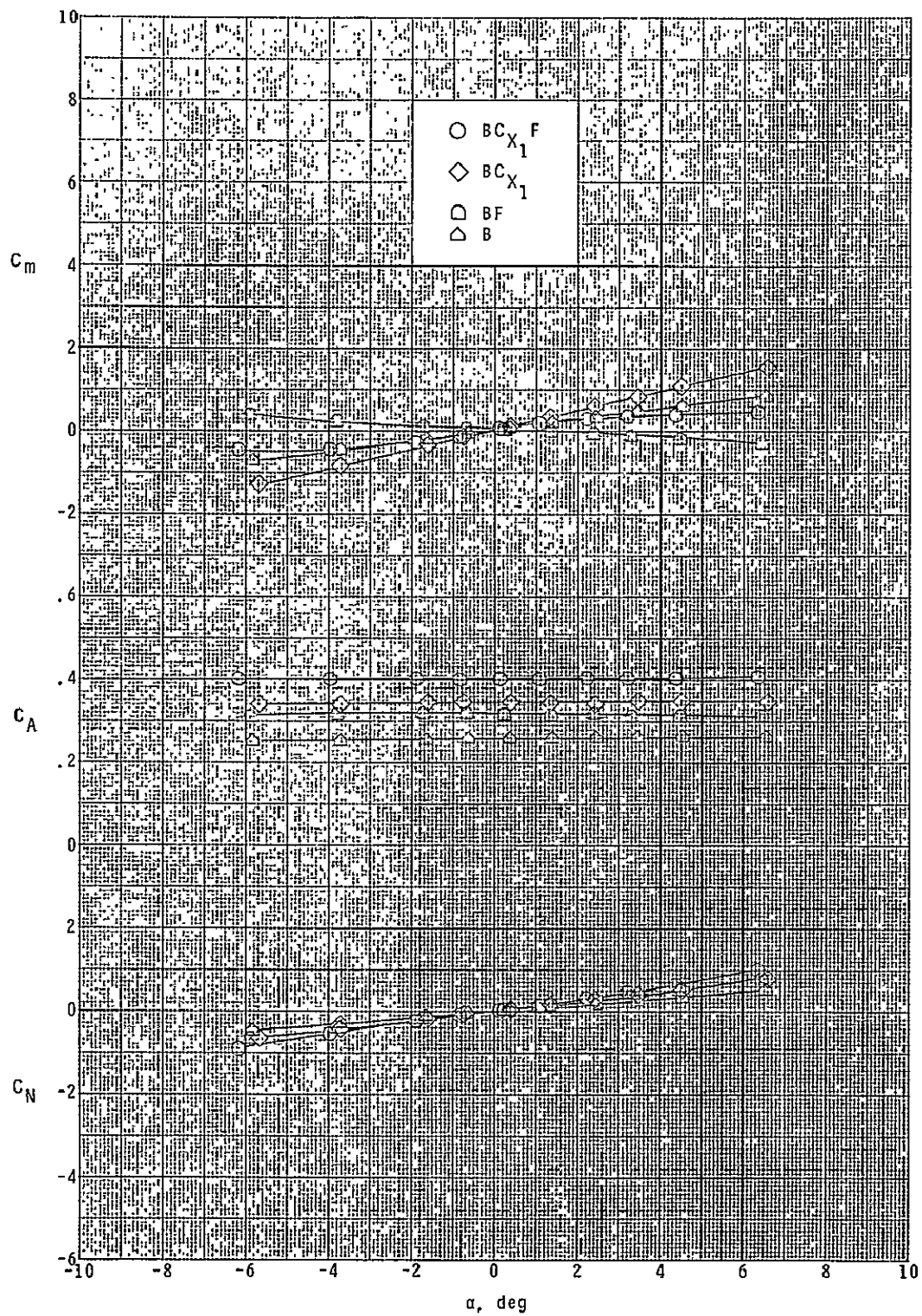
(f) $M = 4.64$.

Figure 4.- Concluded.



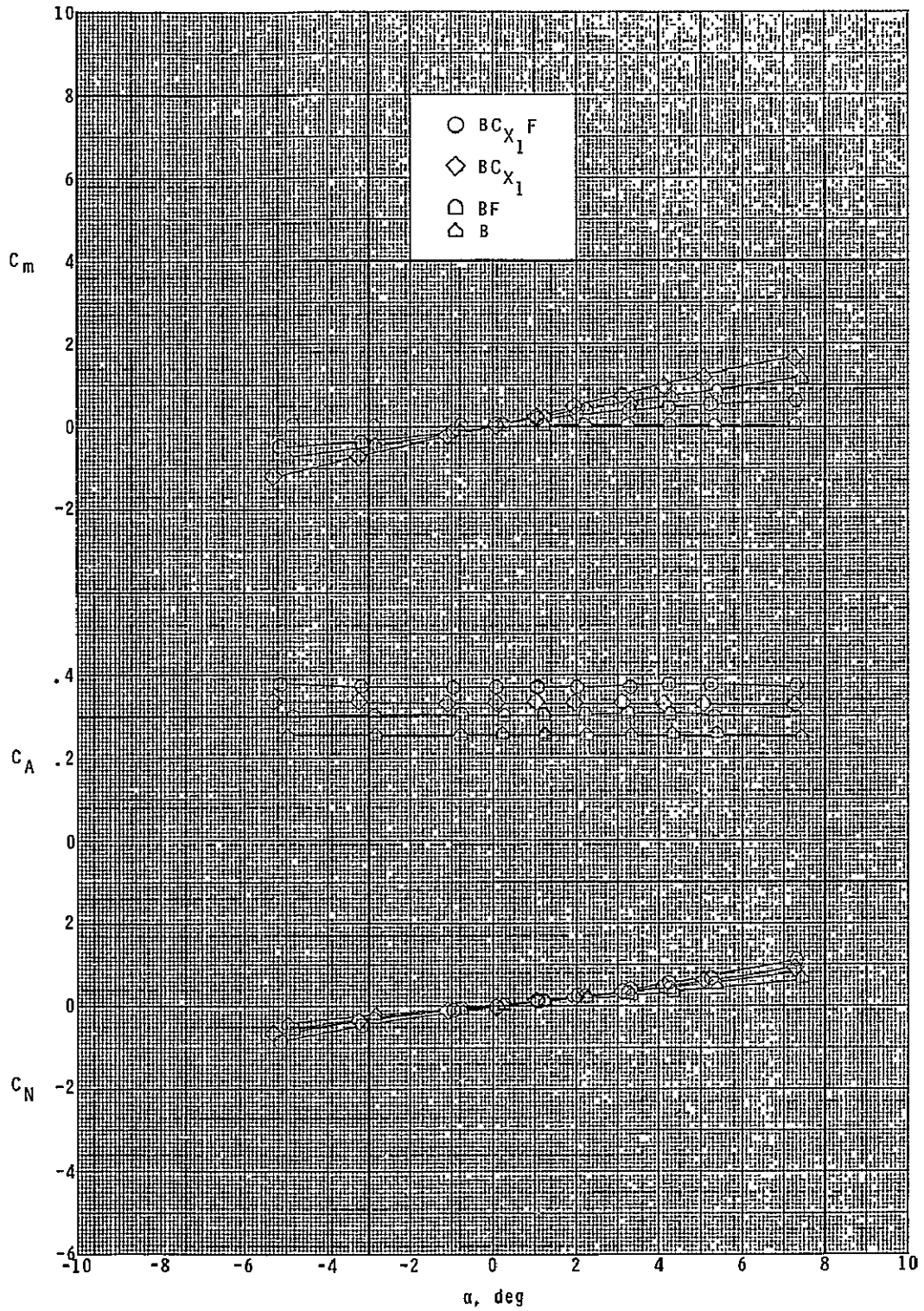
(a) $M = 1.50$.

Figure 5.- Effect of model components on longitudinal characteristics. $\phi = 45^\circ$.



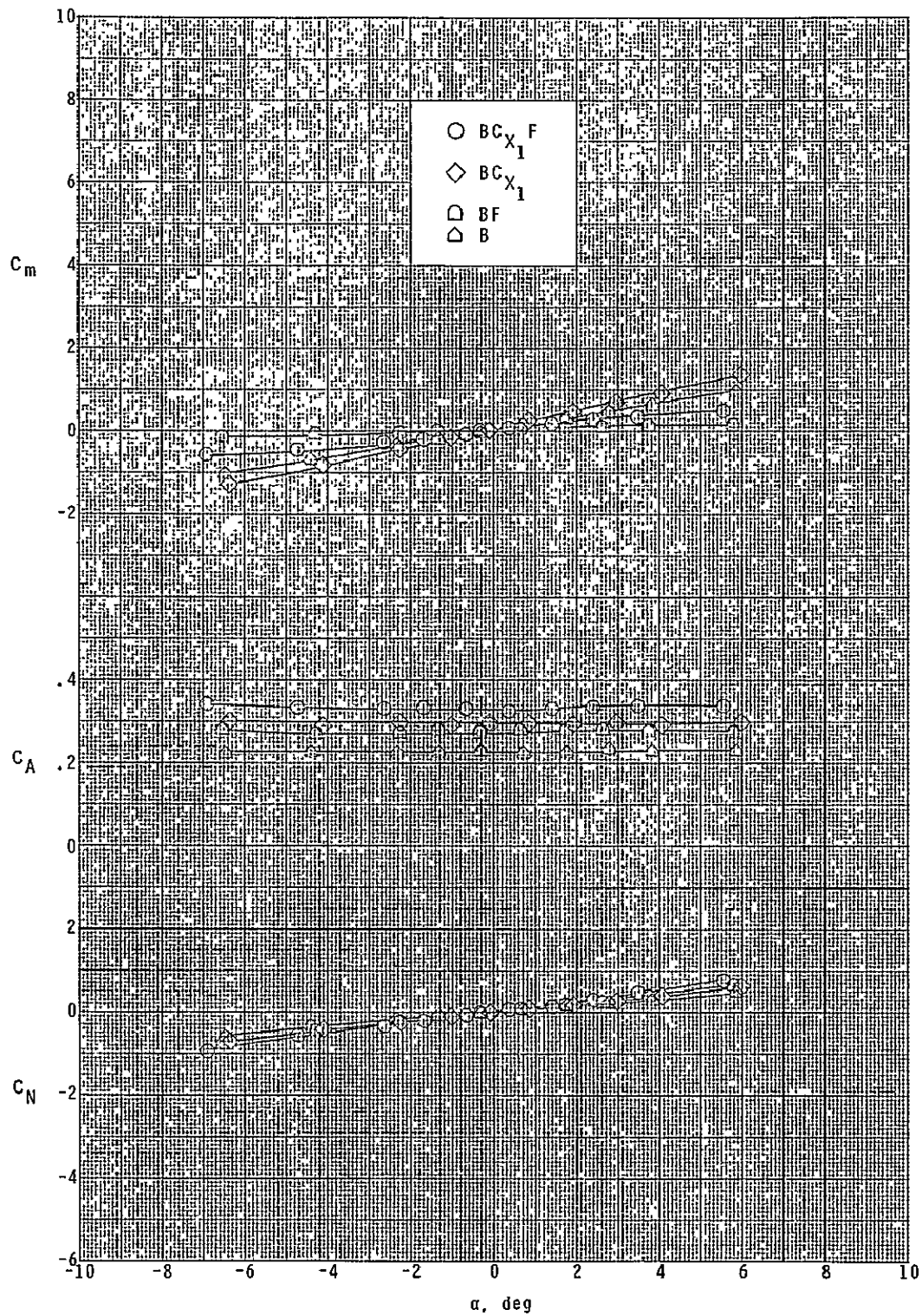
(b) $M = 1.90$.

Figure 5.- Continued.



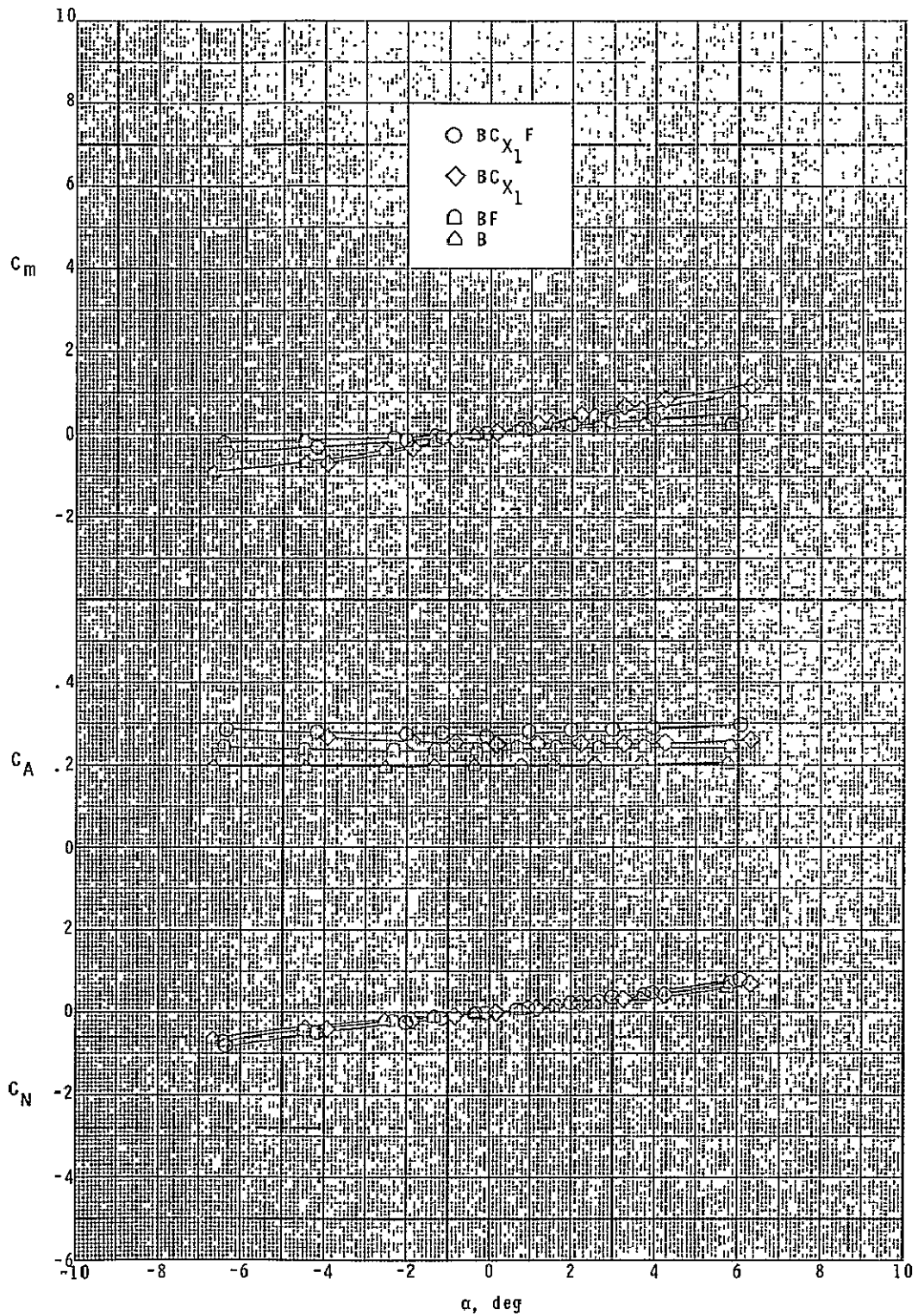
(c) $M = 2.36$.

Figure 5.- Continued.



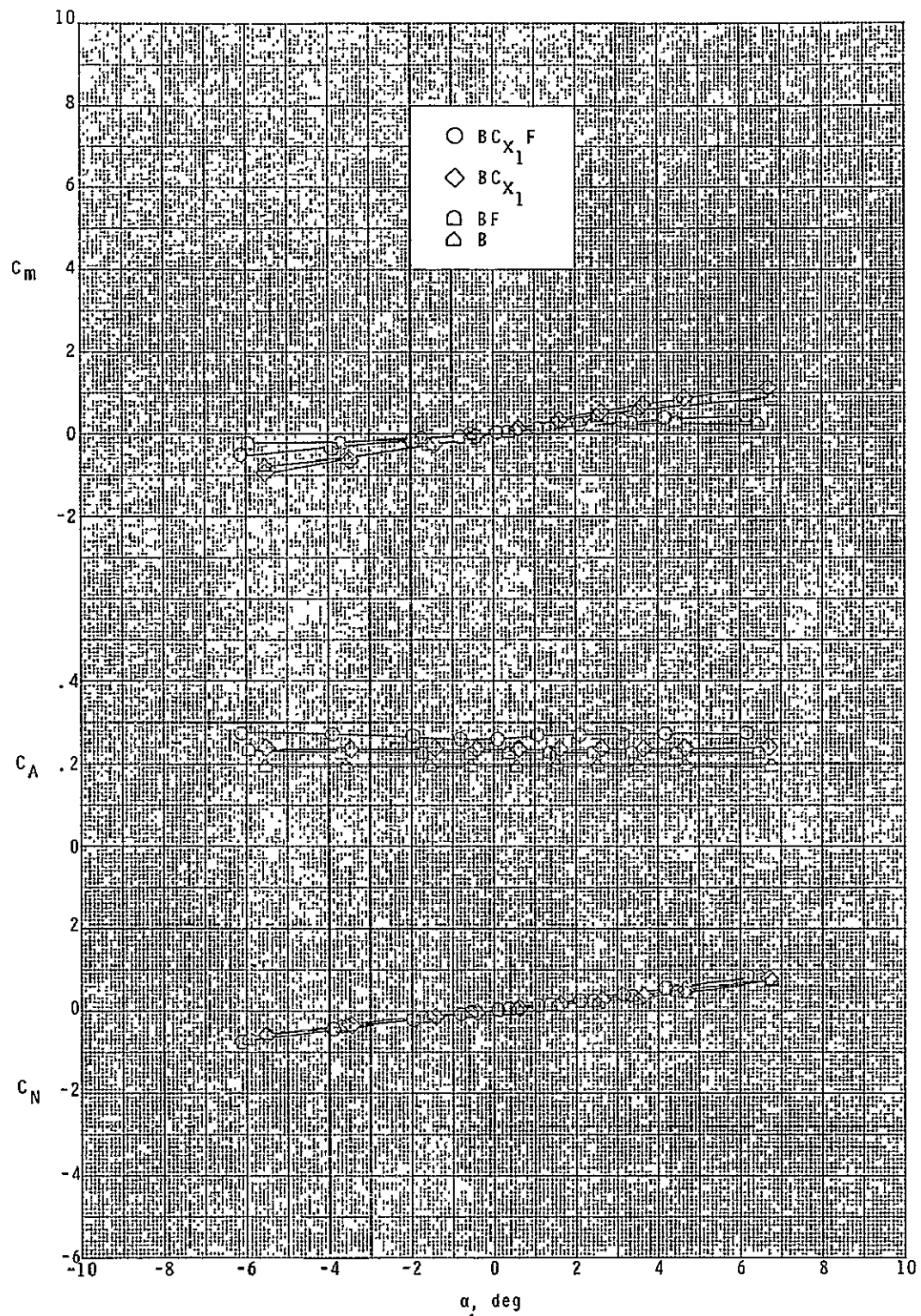
(d) $M = 2.87$.

Figure 5.- Continued.



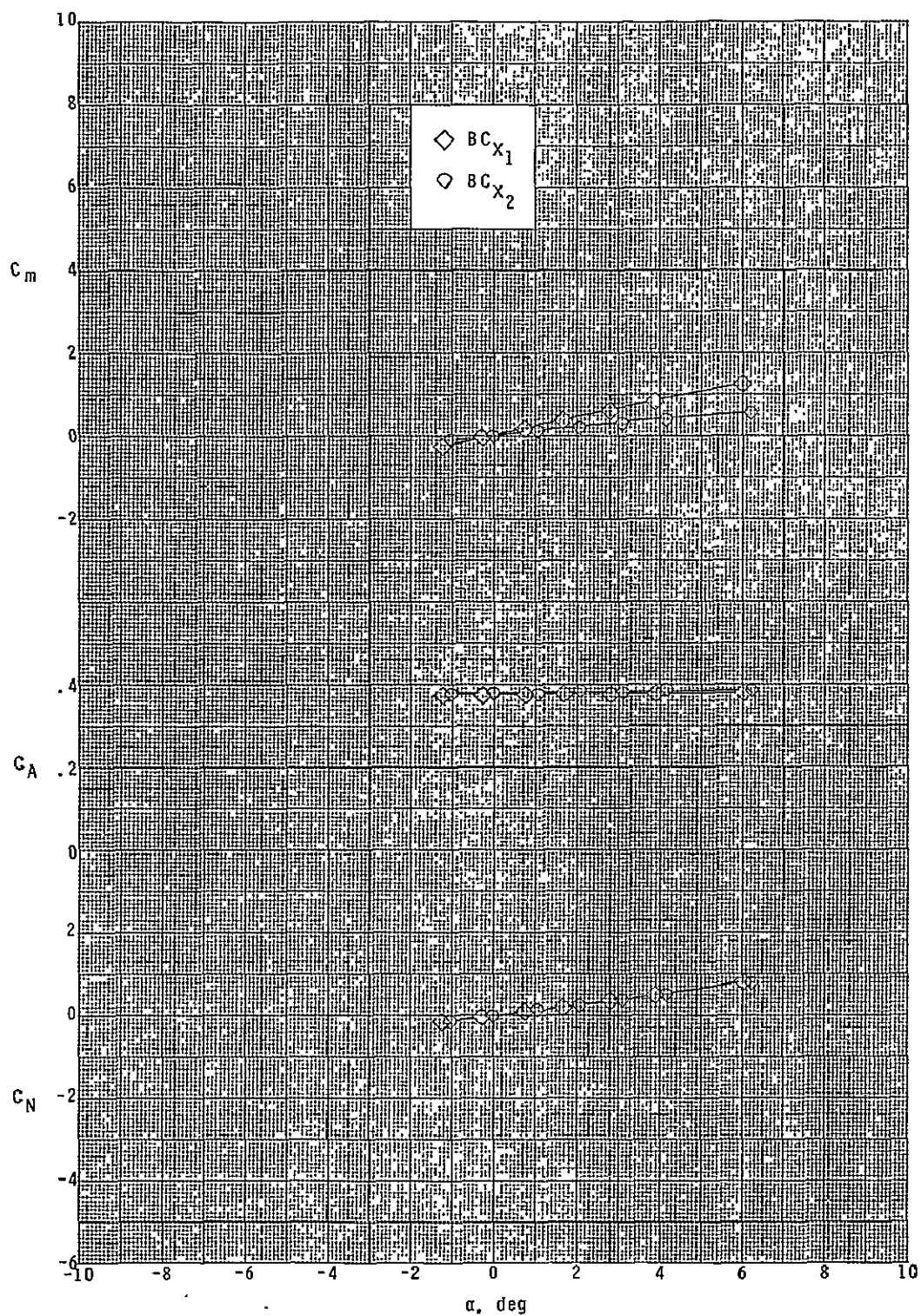
(e) $M = 3.85$.

Figure 5.- Continued.



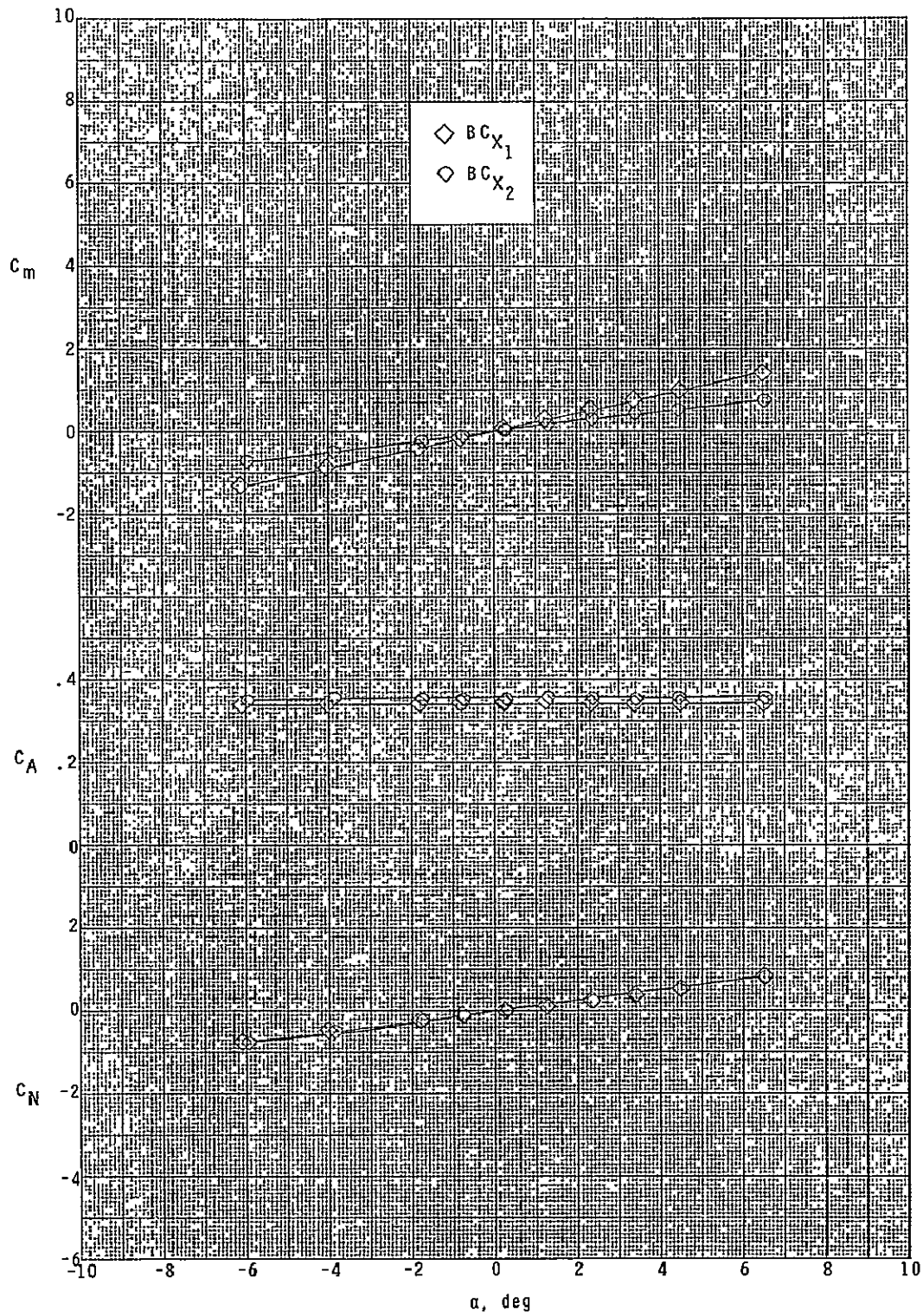
(f) $M = 4.64$.

Figure 5.- Concluded.



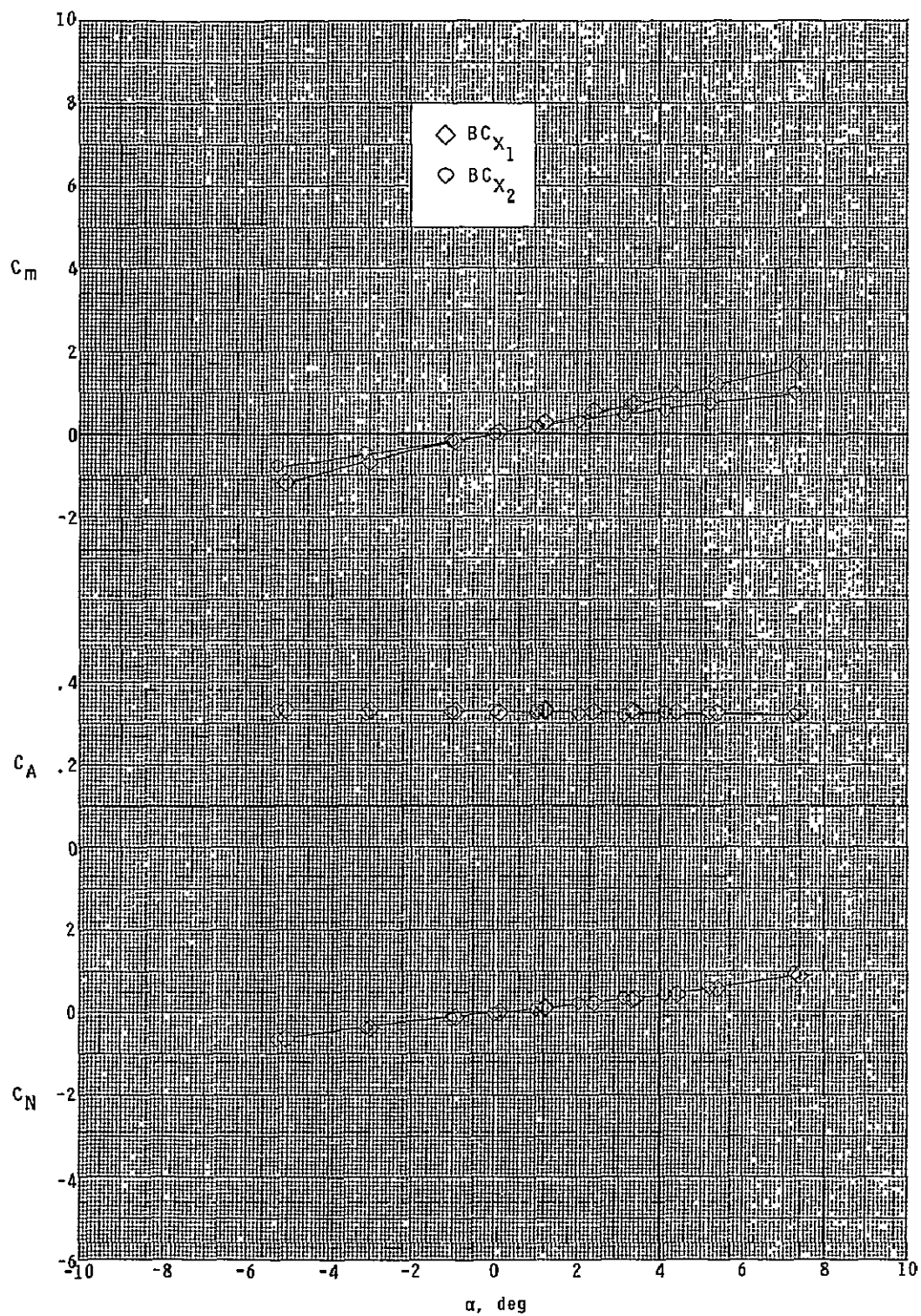
(a) $M = 1.50$.

Figure 6.- Effect of wing position on the longitudinal characteristics of the wing-body configuration. $\phi = 0^\circ$.



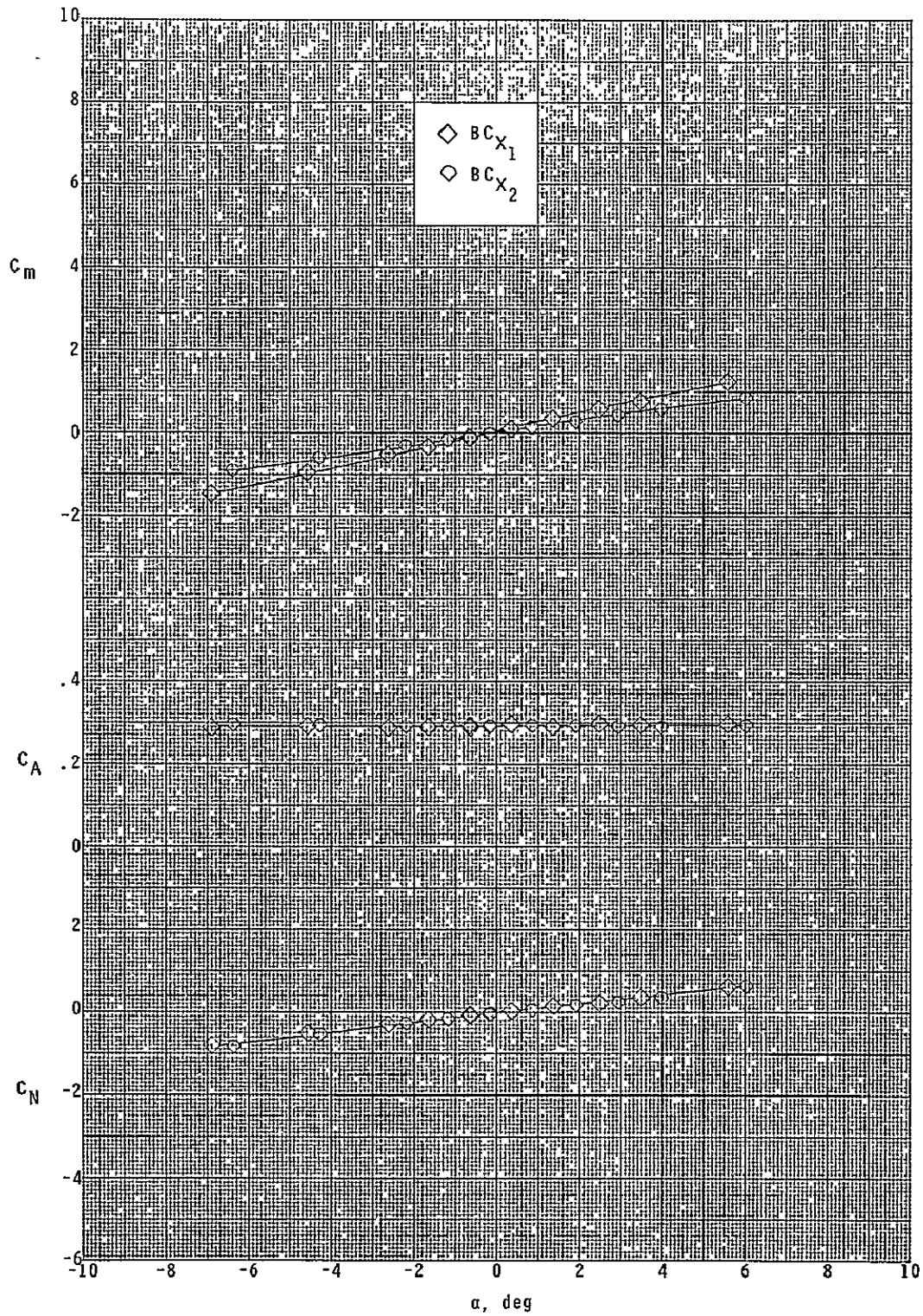
(b) $M = 1.90$.

Figure 6.- Continued.



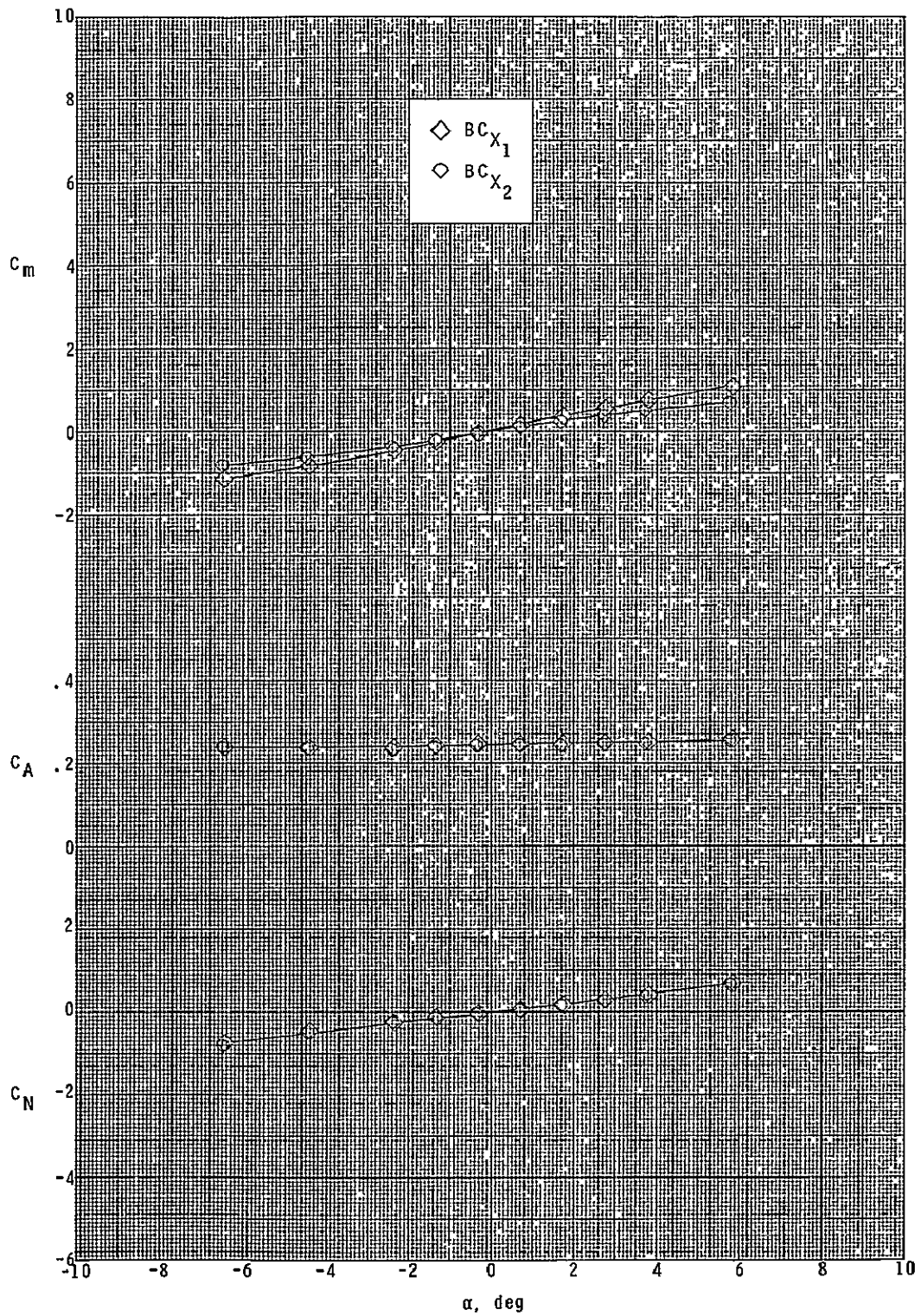
(c) $M = 2.36$.

Figure 6.- Continued.



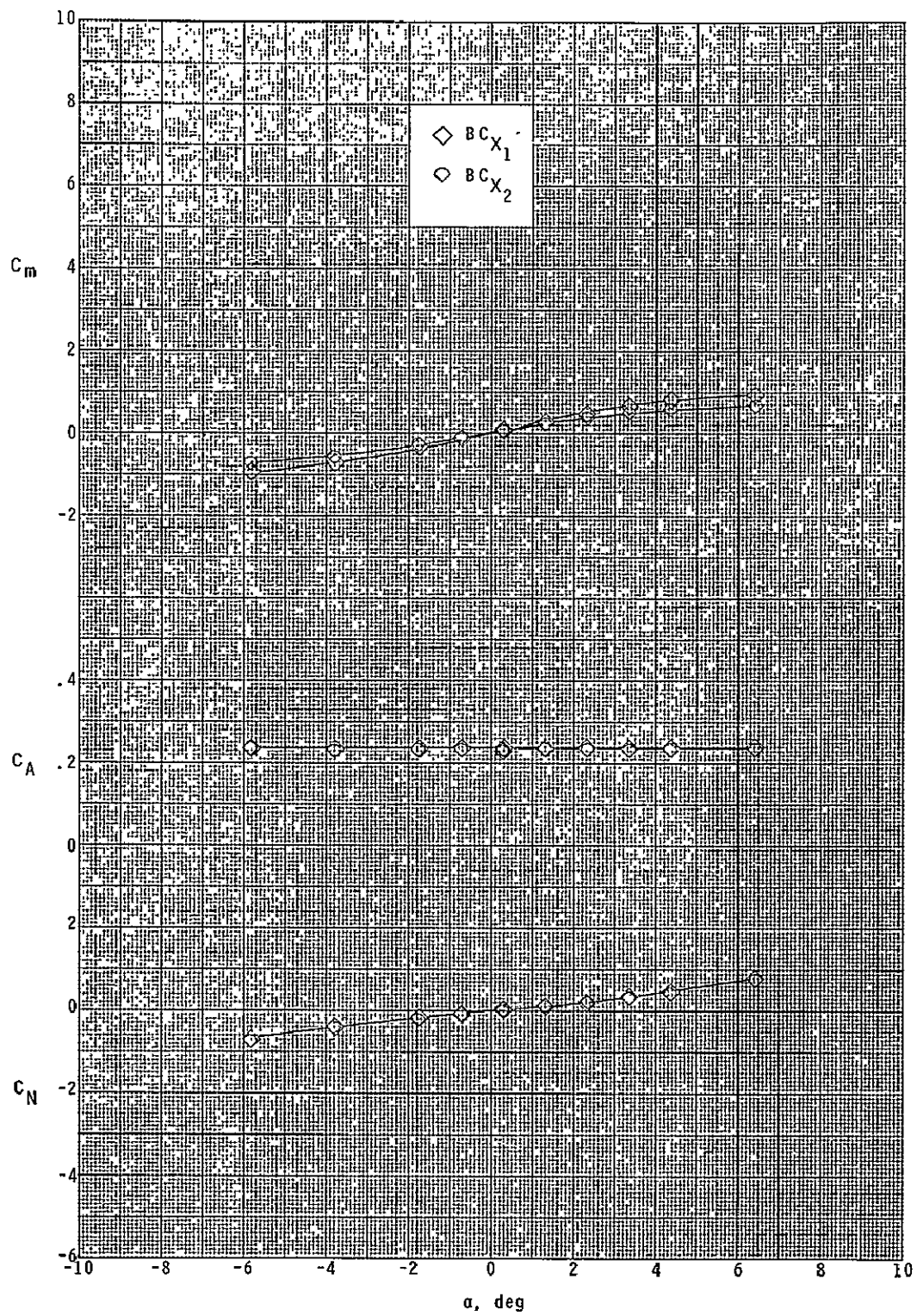
(d) $M = 2.87$.

Figure 6.- Continued.



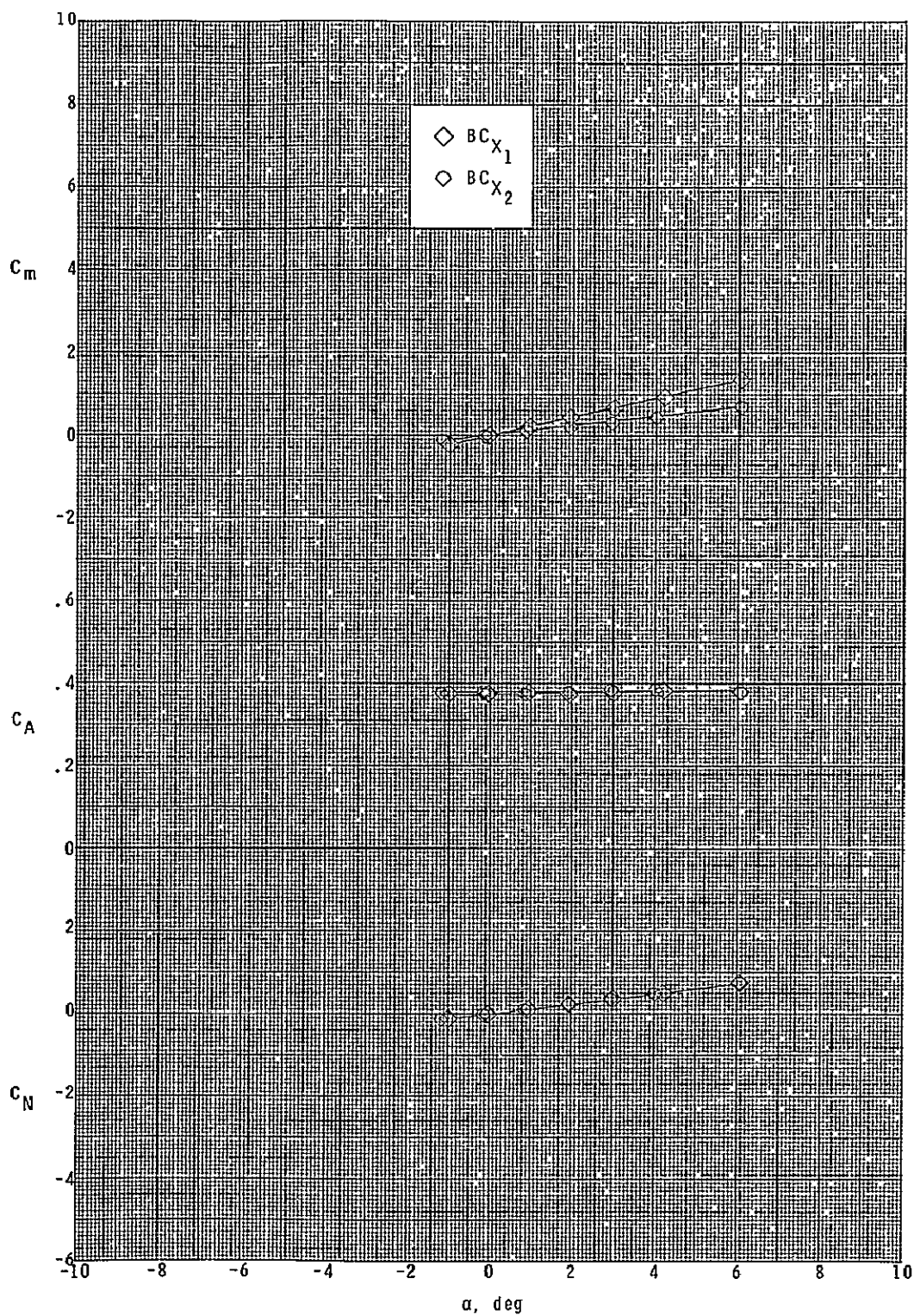
(e) $M = 3.85$.

Figure 6.- Continued.



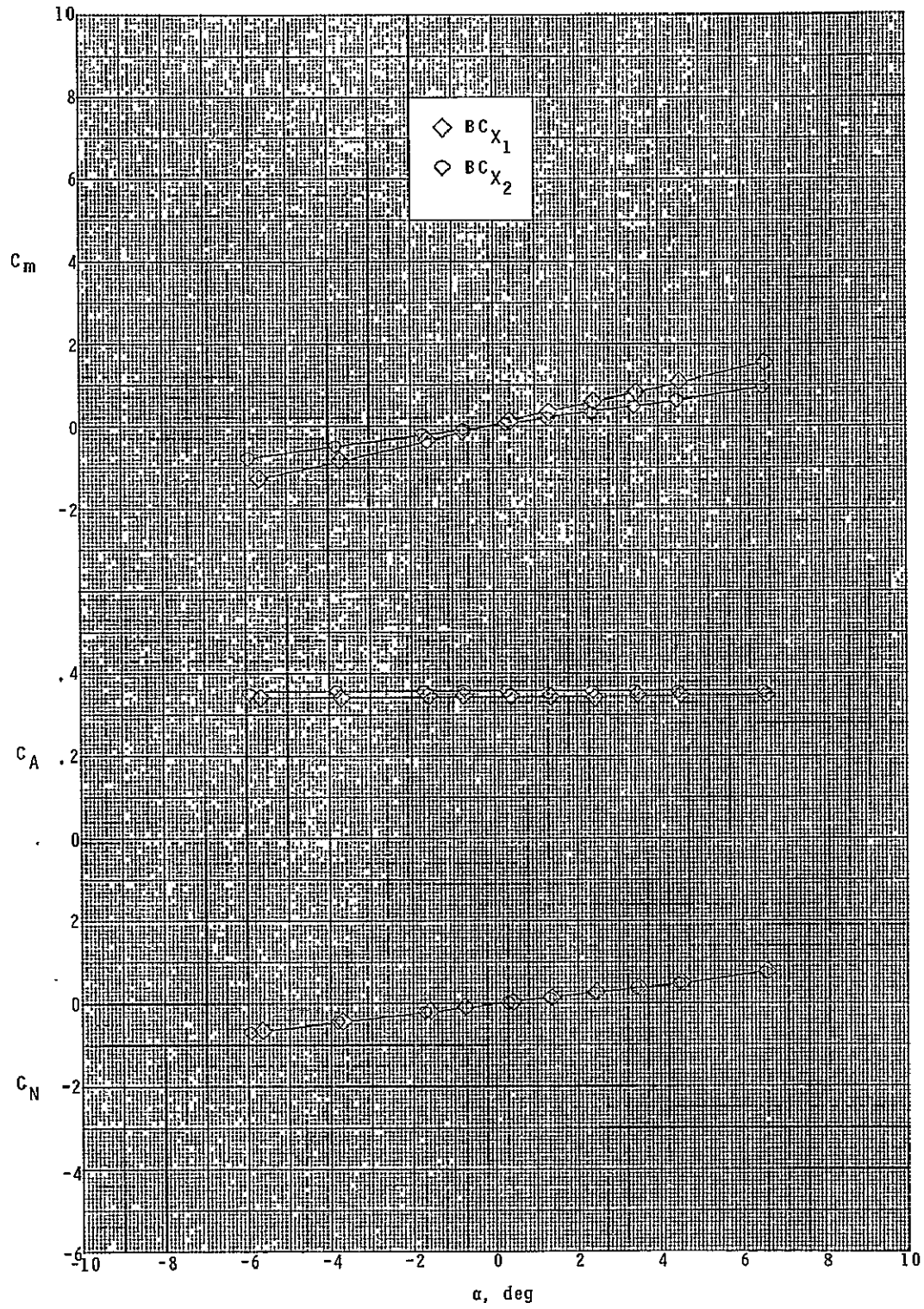
(f) $M = 4.64$.

Figure 6.- Concluded.



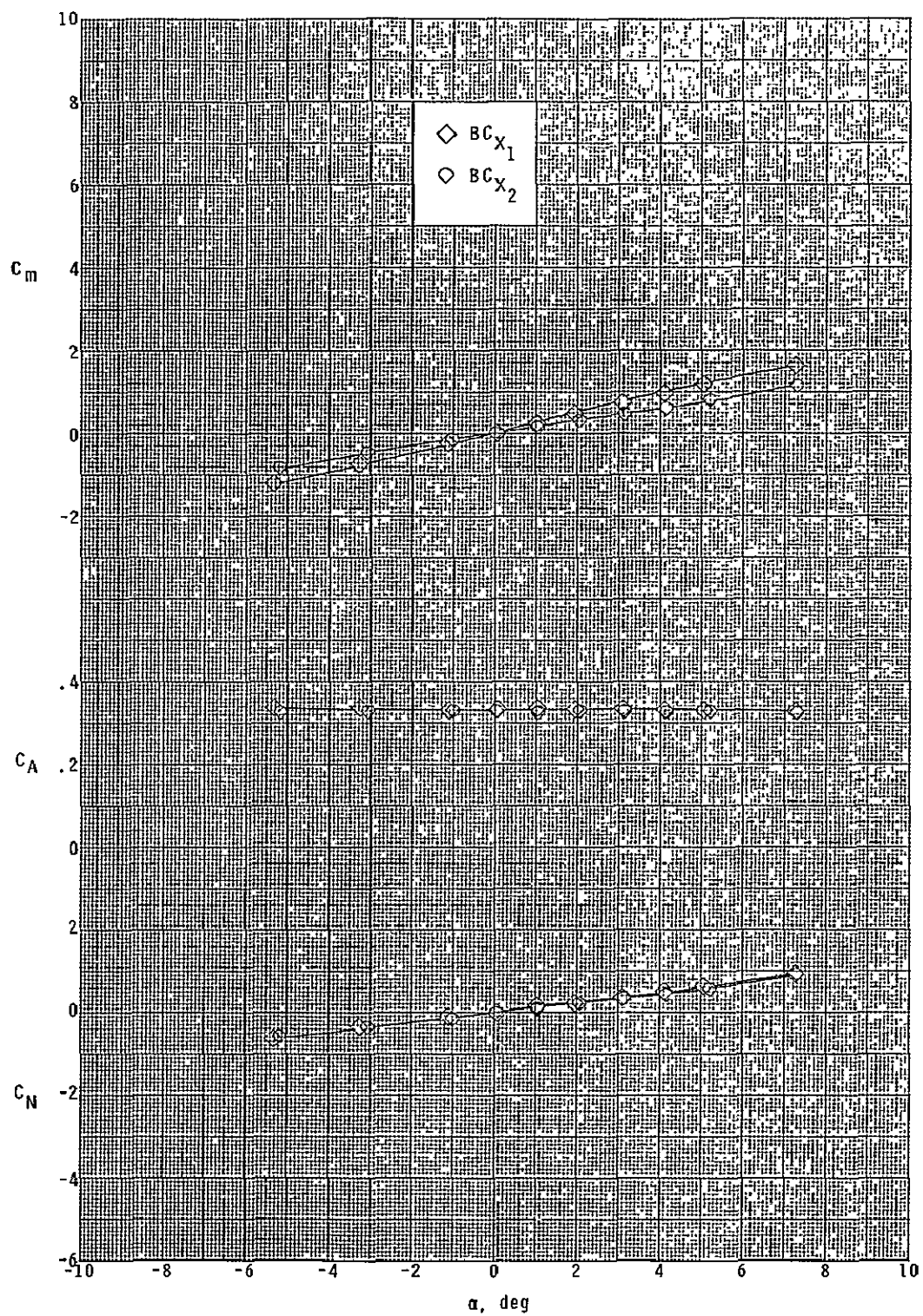
(a) $M = 1.50$.

Figure 7.- Effect of wing position on the longitudinal characteristics of the wing-body configuration. $\phi = 45^\circ$.



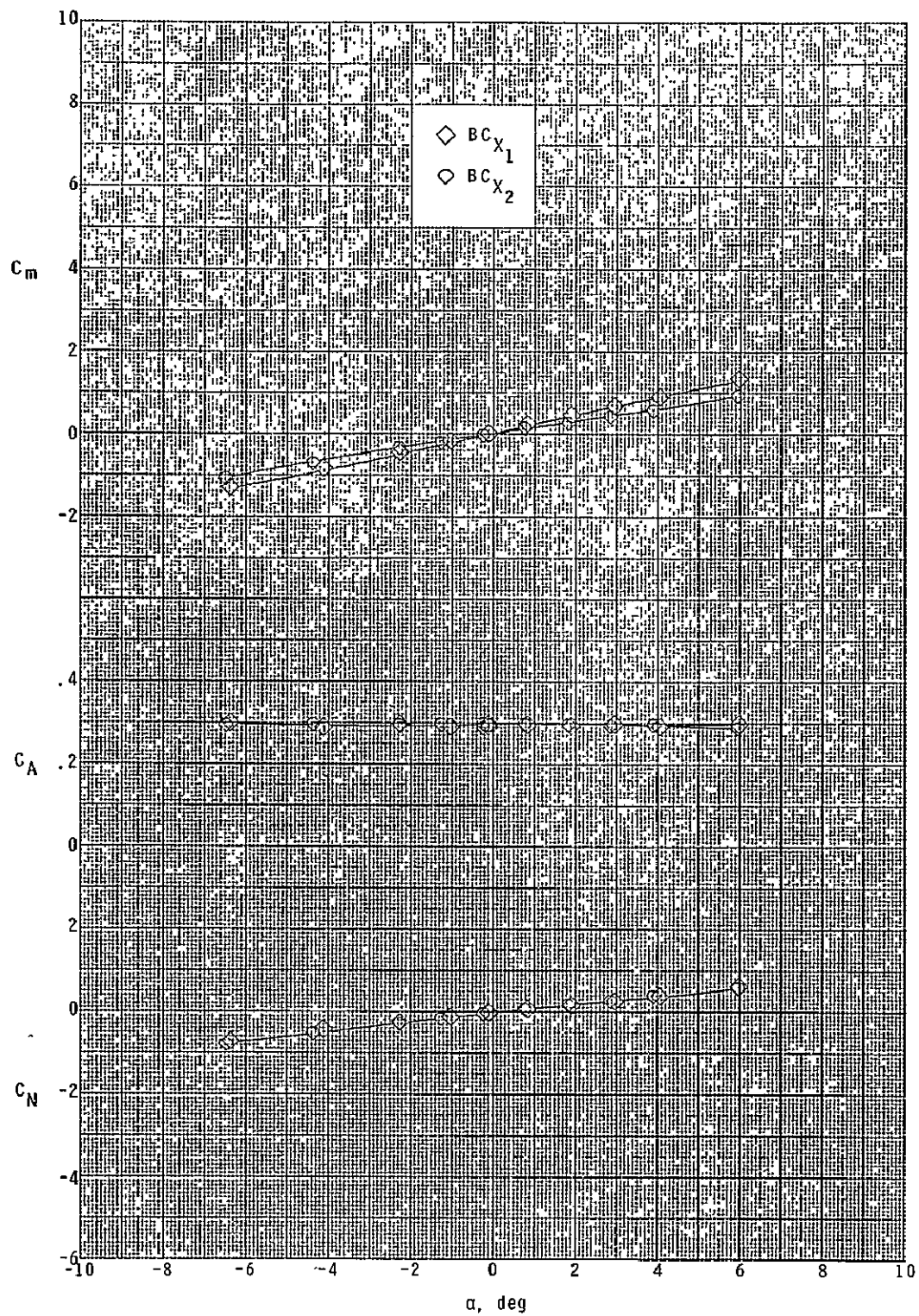
(b) $M = 1.90$.

Figure 7.- Continued.



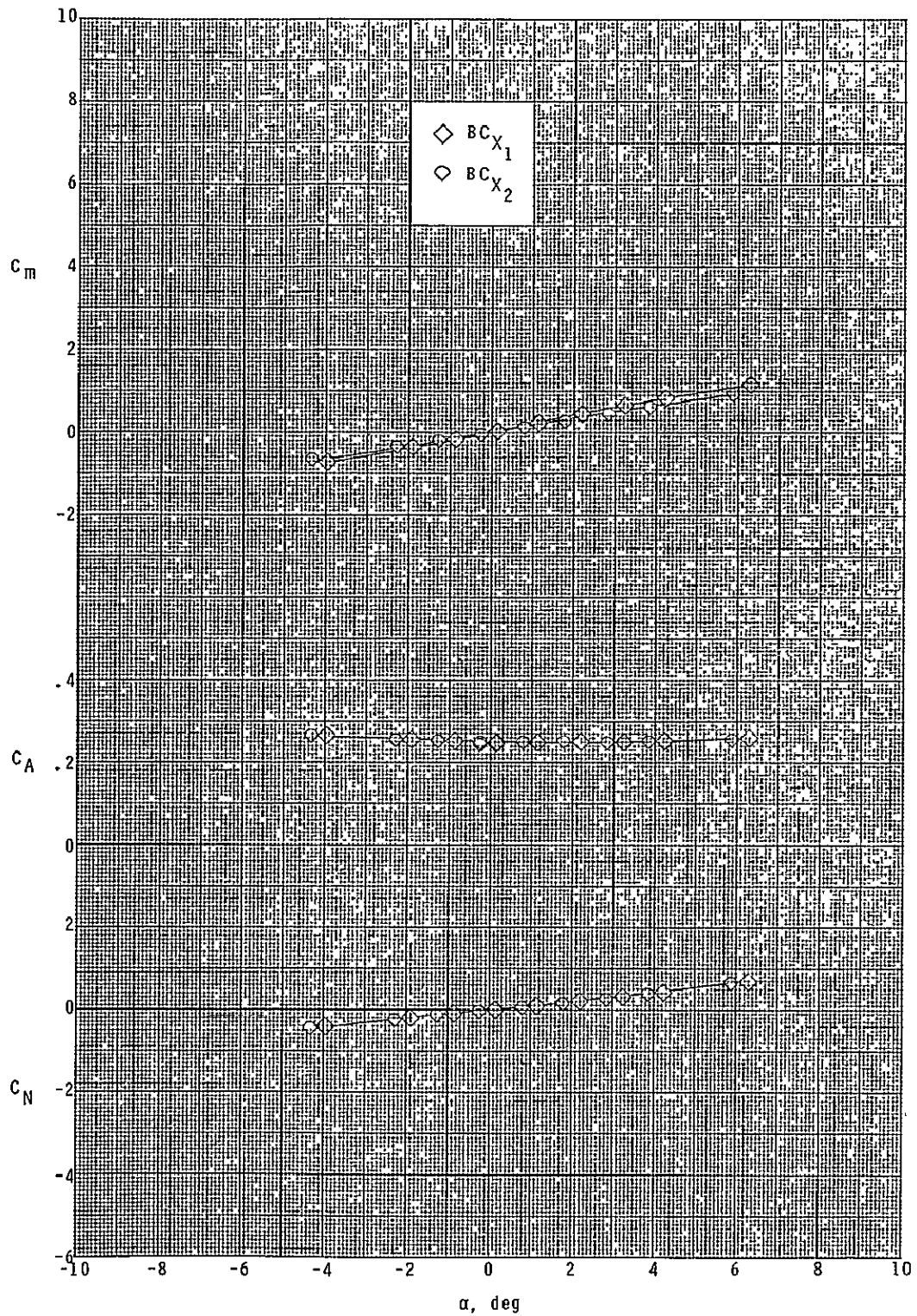
(c) $M = 2.36$.

Figure 7.- Continued.



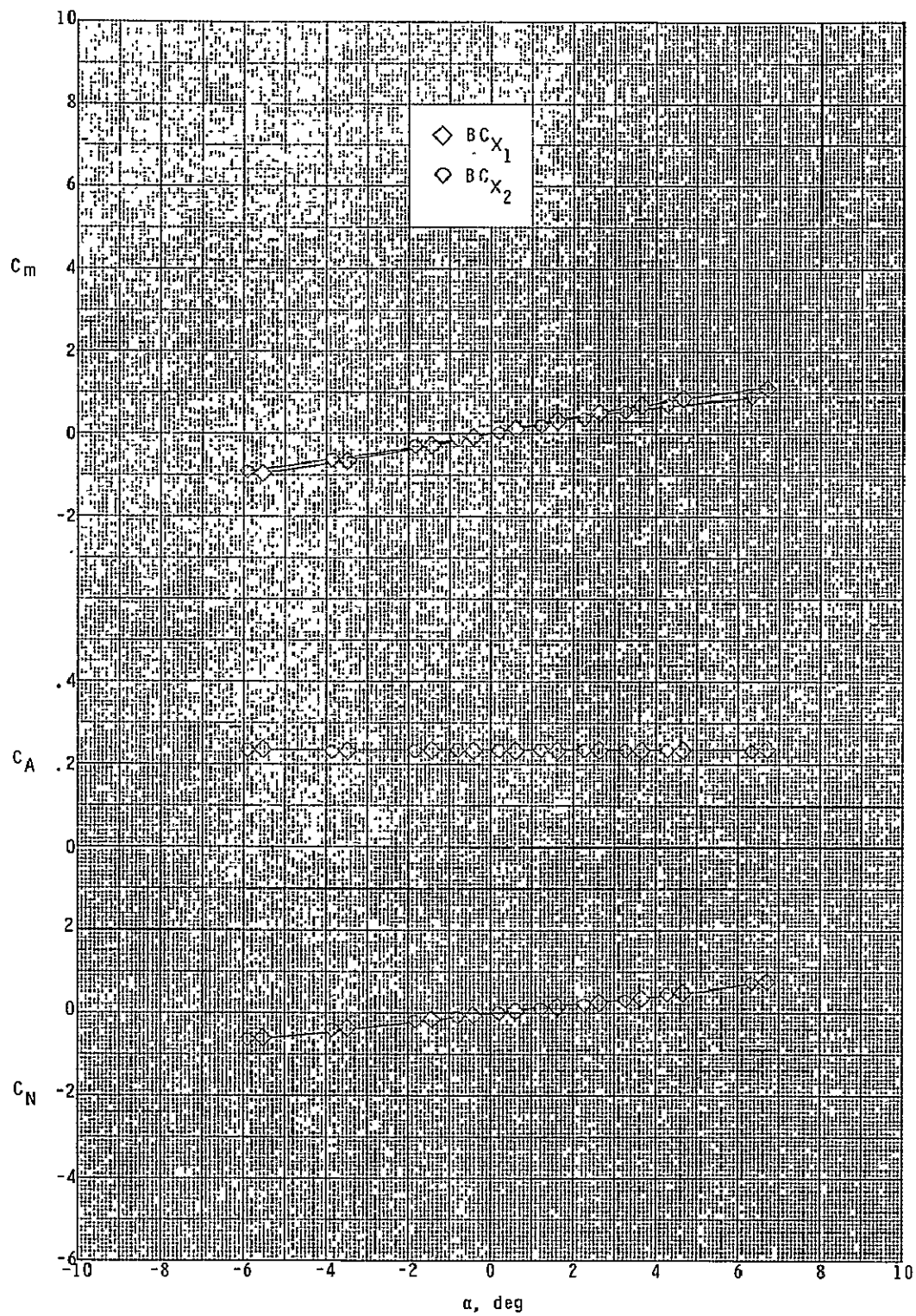
(d) $M = 2.87$.

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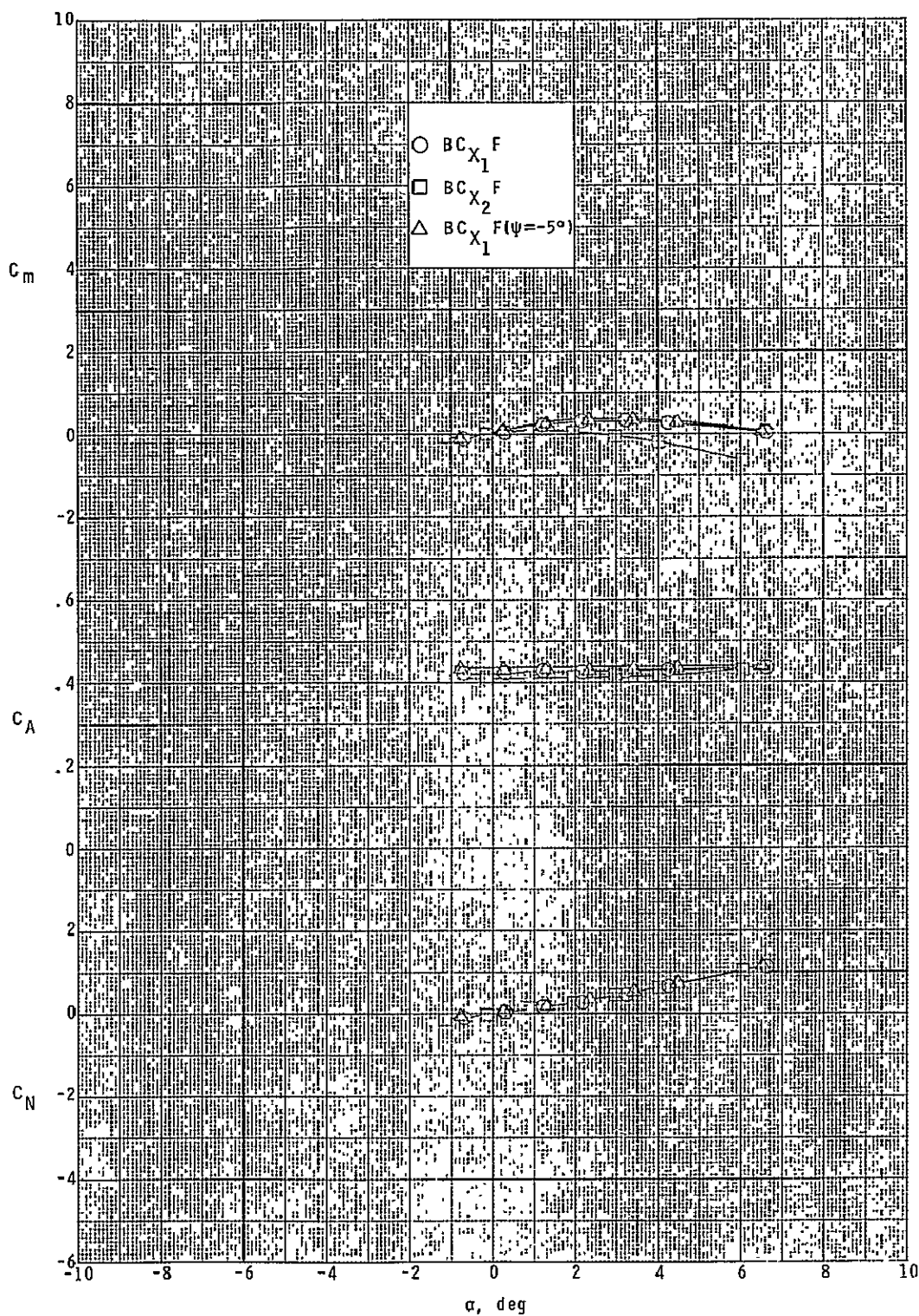
(e) $M = 3.85$.

Figure 7.- Continued.



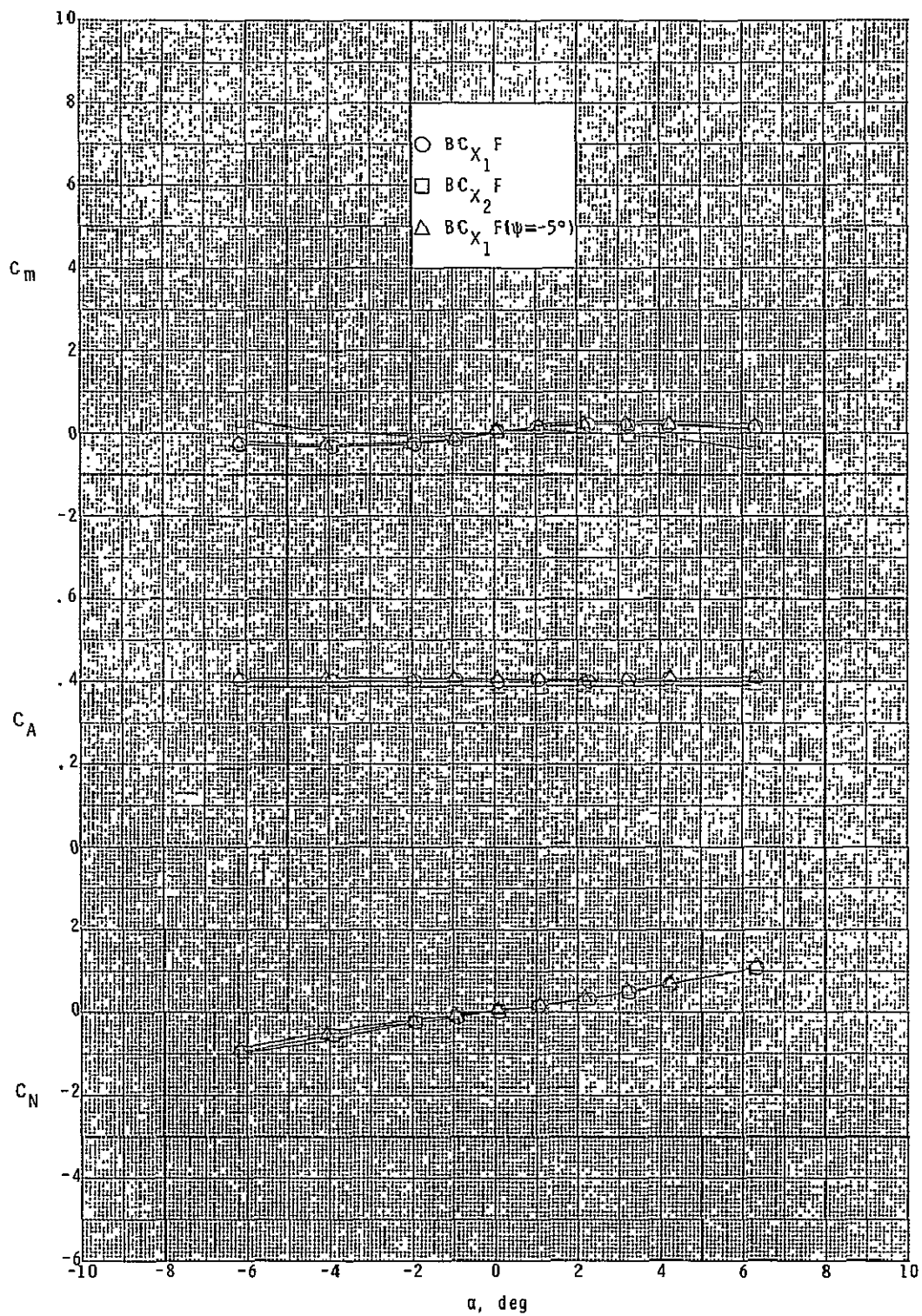
(f) $M = 4.64$.

Figure 7.- Concluded.



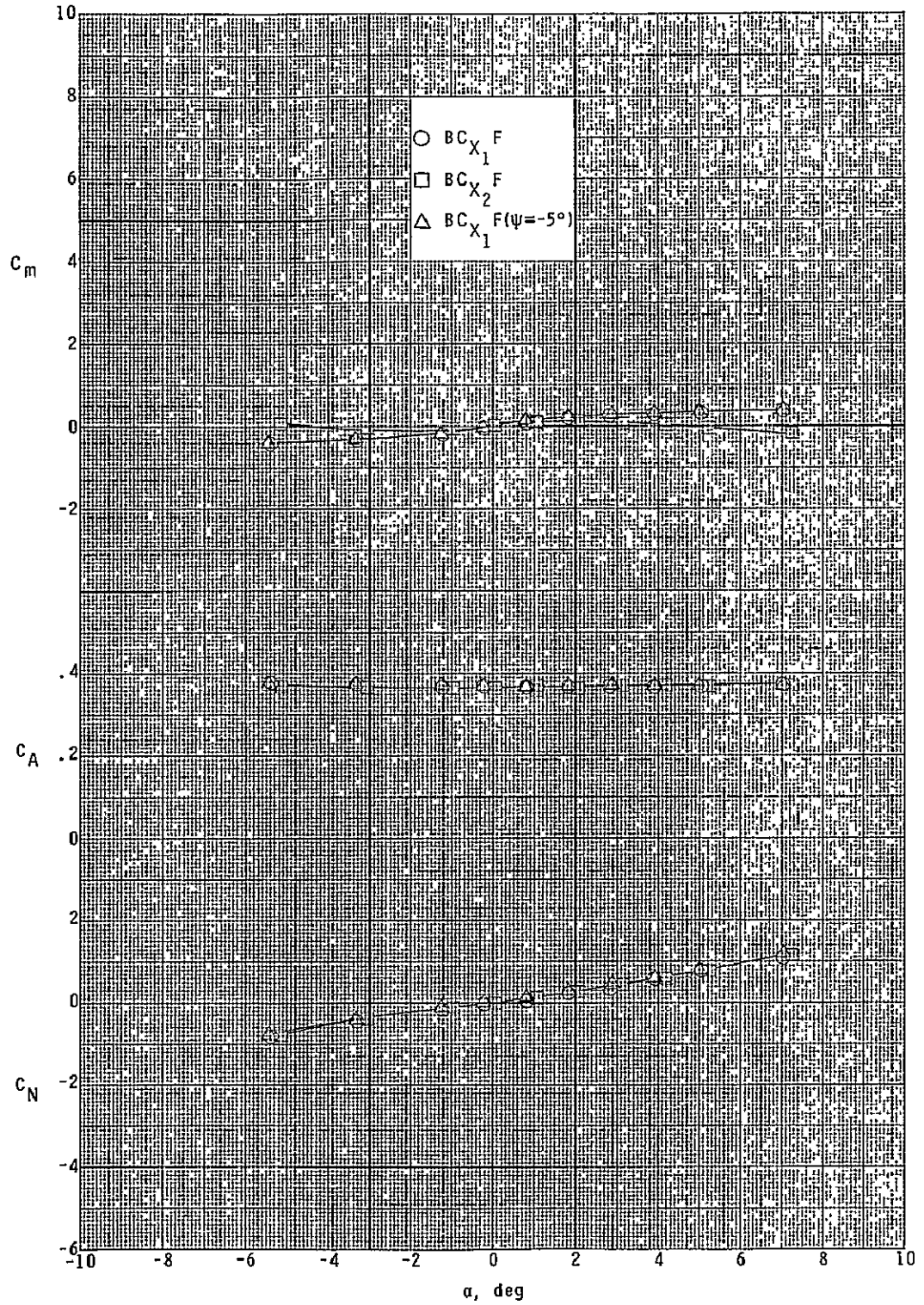
(a) $M = 1.50$.

Figure 8.- Effect of wing position on the longitudinal characteristics of the complete model. $\phi = 0^\circ$.



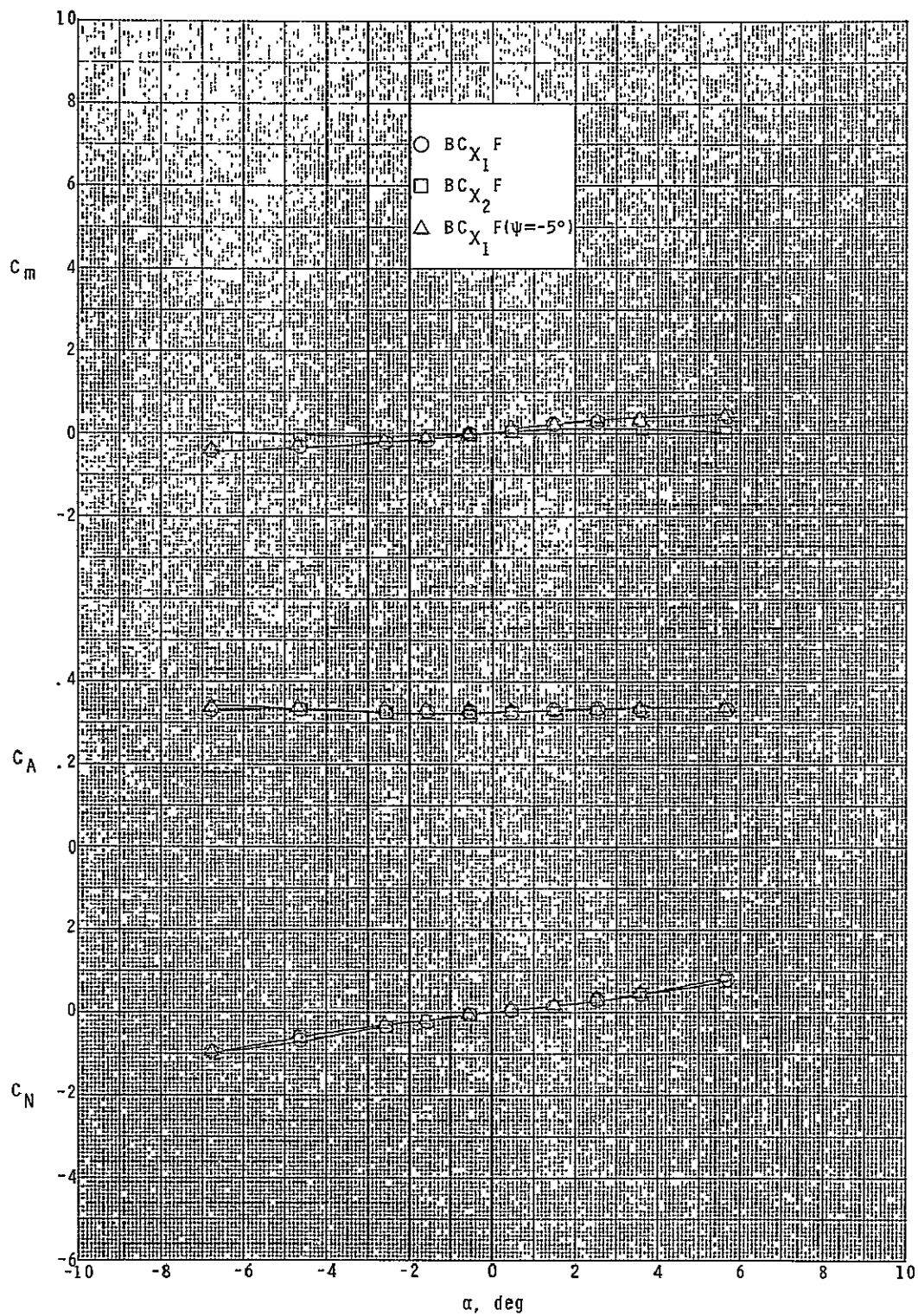
(b) $M = 1.90$.

Figure 8.- Continued.



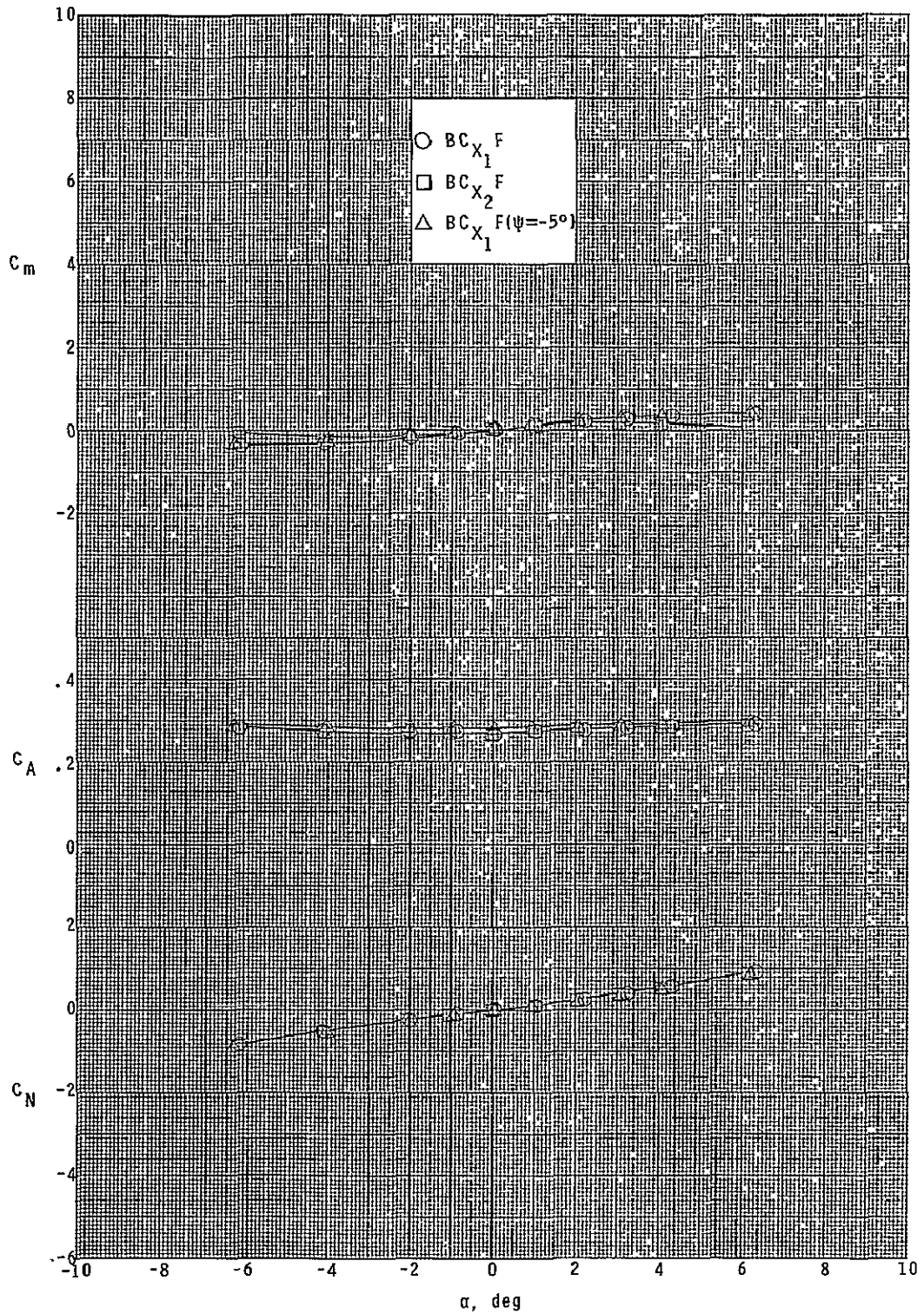
(c) $M = 2.36$.

Figure 8.- Continued.



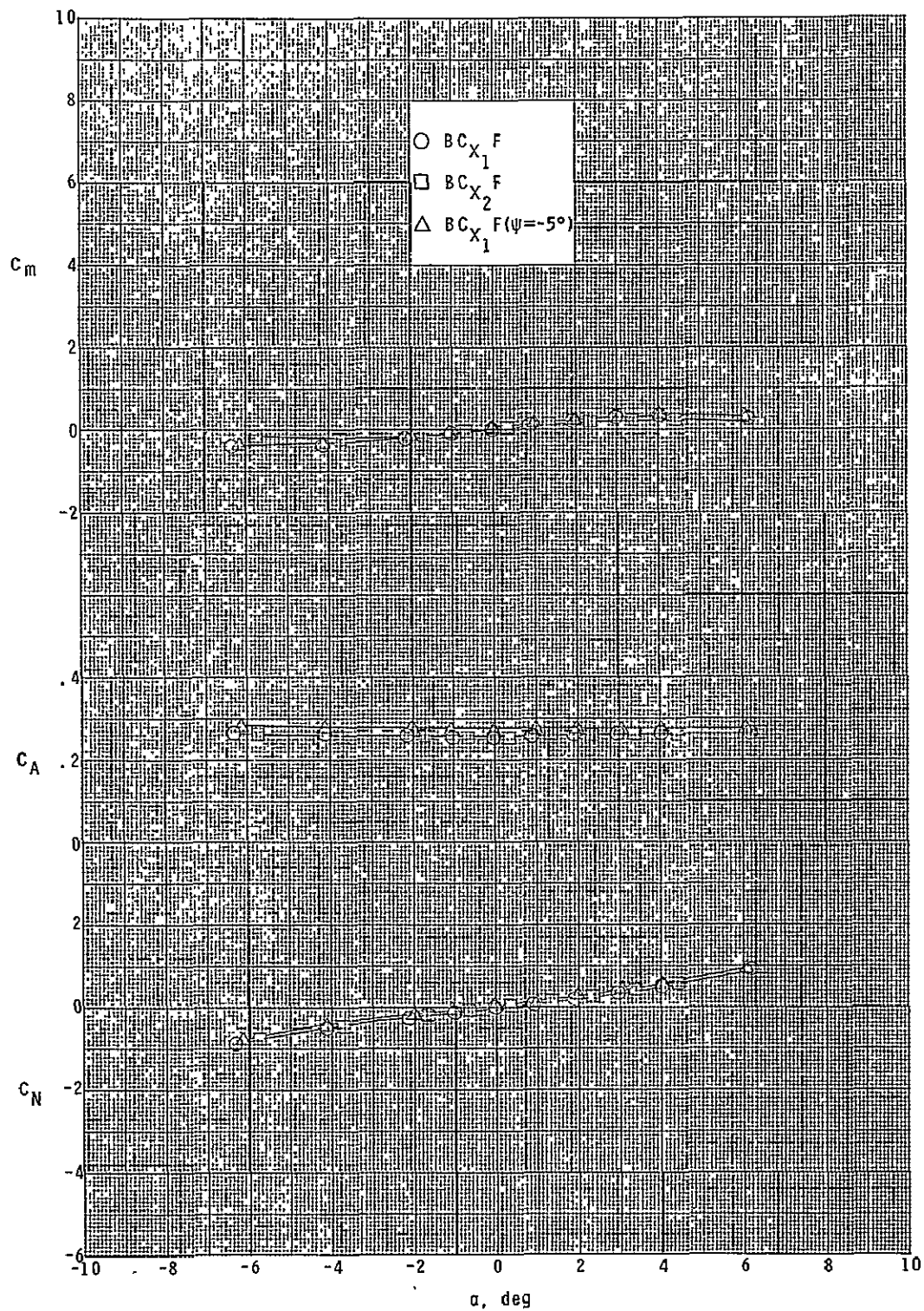
(d) $M = 2.87$.

Figure 8.- Continued.



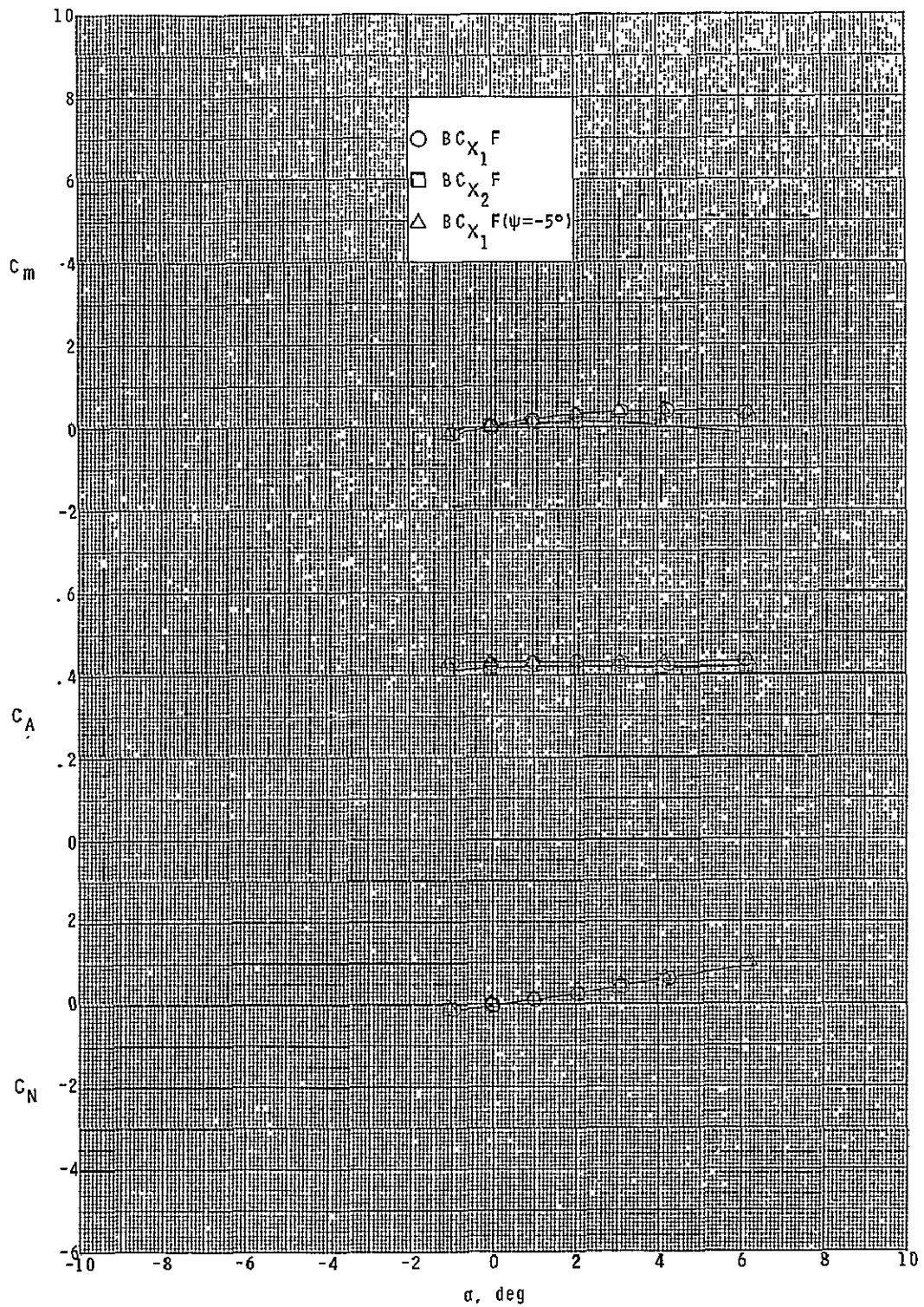
(e) $M = 3.85$.

Figure 8.- Continued.



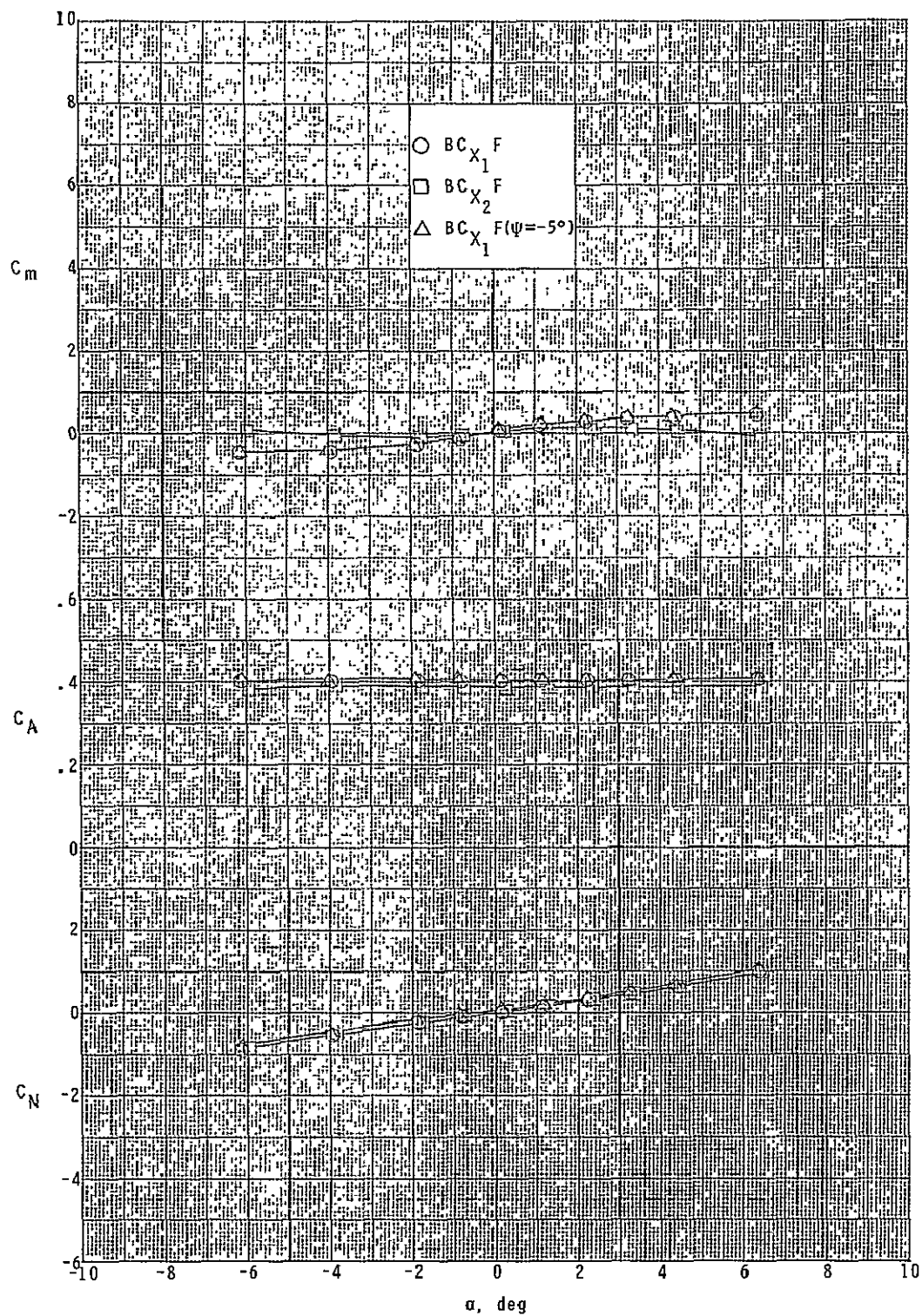
(f) $M = 4.64$.

Figure 8.- Concluded.



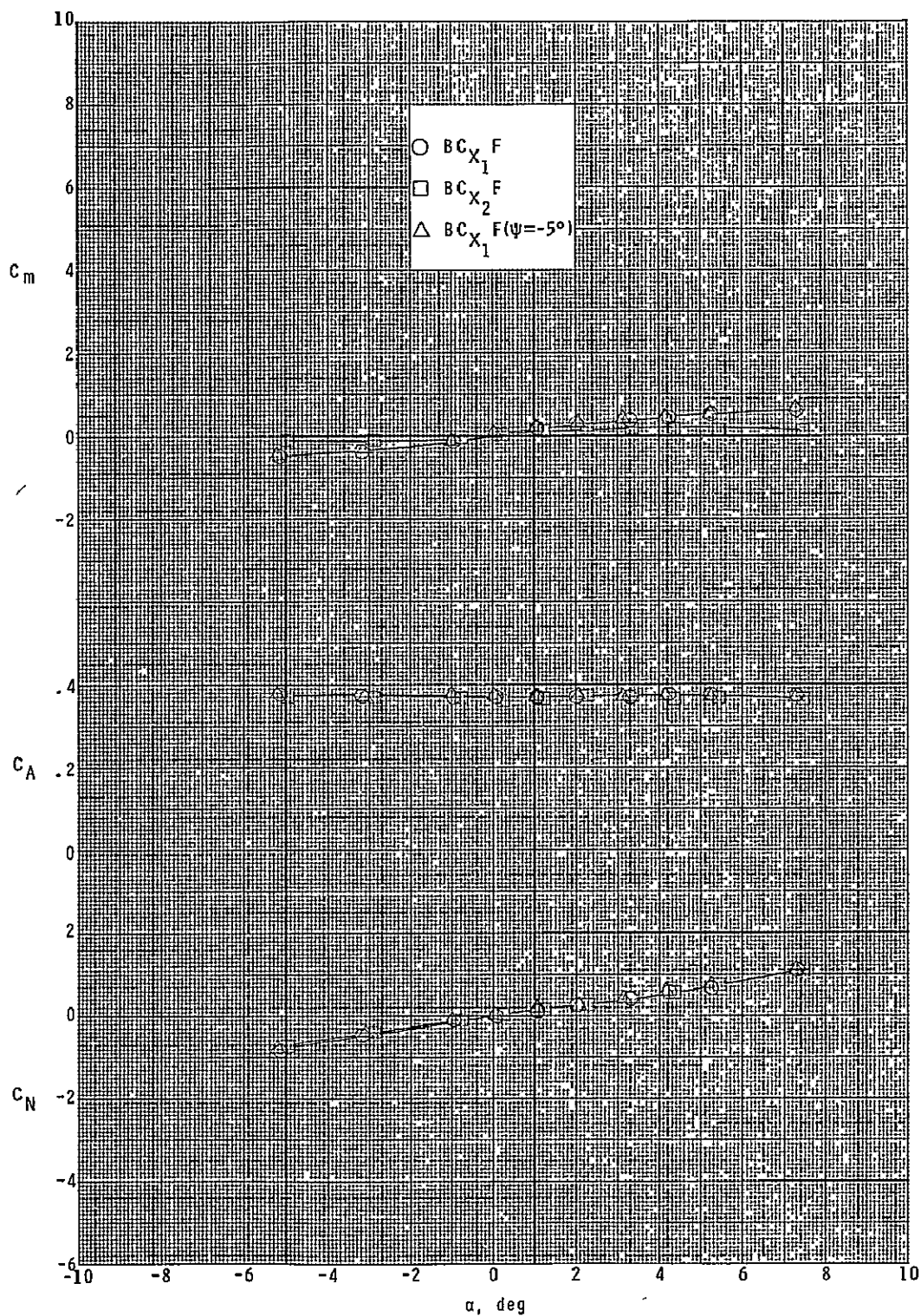
(a) $M = 1.50$.

Figure 9.- Effect of wing position on the longitudinal characteristics of the complete model. $\phi = 45^\circ$.



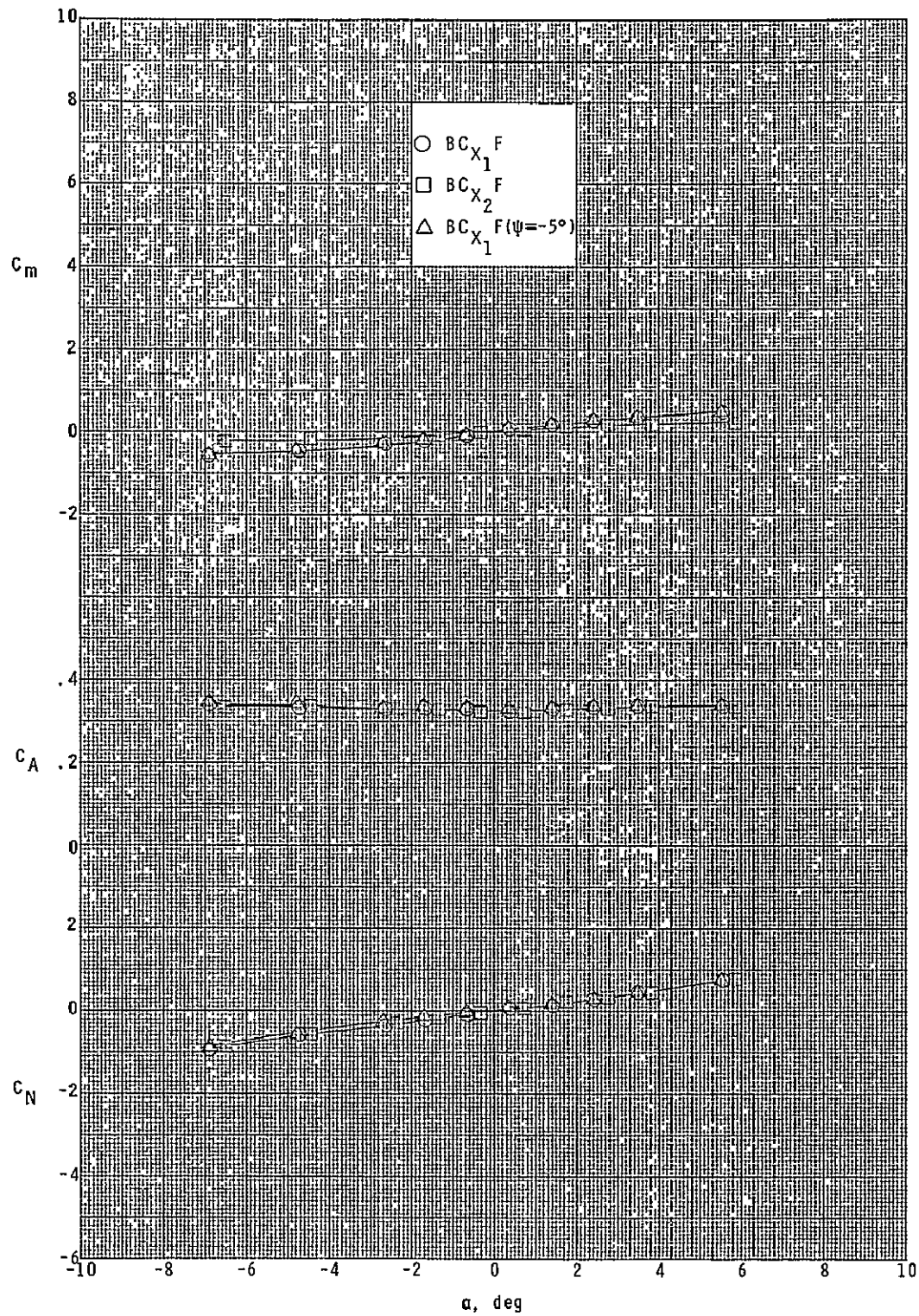
(b) $M = 1.90$.

Figure 9.- Continued.



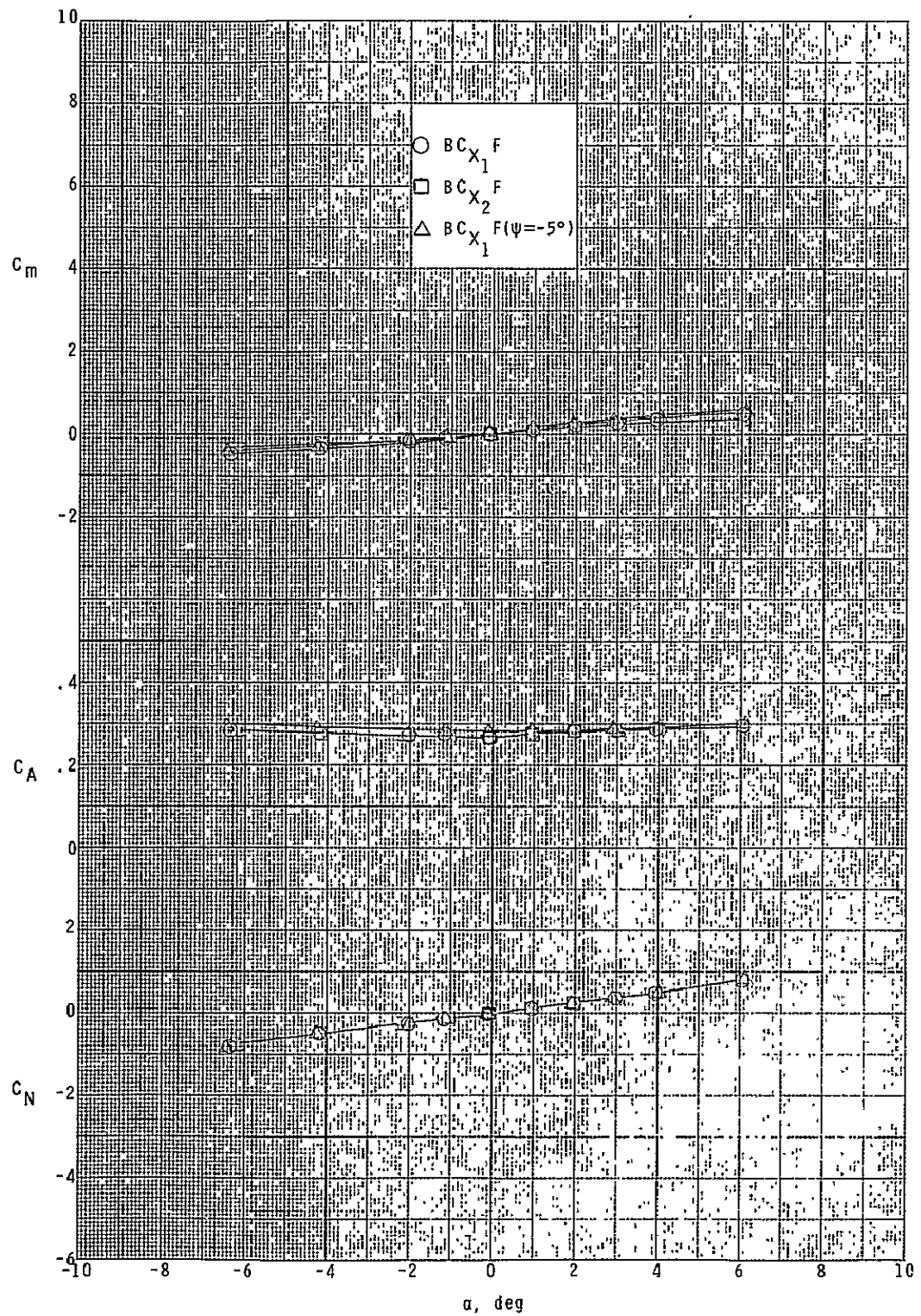
(c) $M = 2.36$.

Figure 9.- Continued.



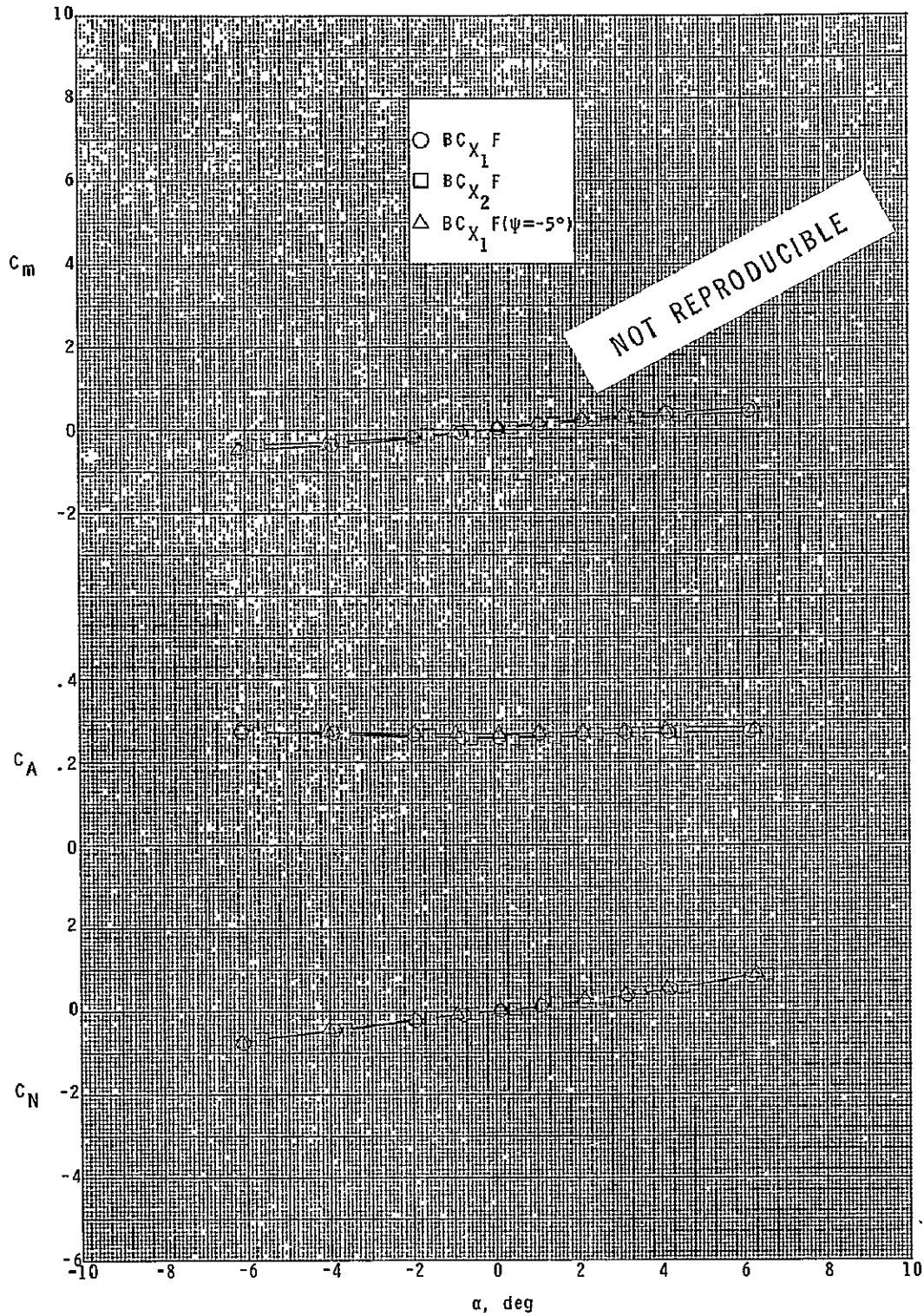
(d) $M = 2.87$.

Figure 9.- Continued.



(e) $M = 3.85$.

Figure 9.- Continued.



(f) $M = 4.64$.

Figure 9.- Concluded.

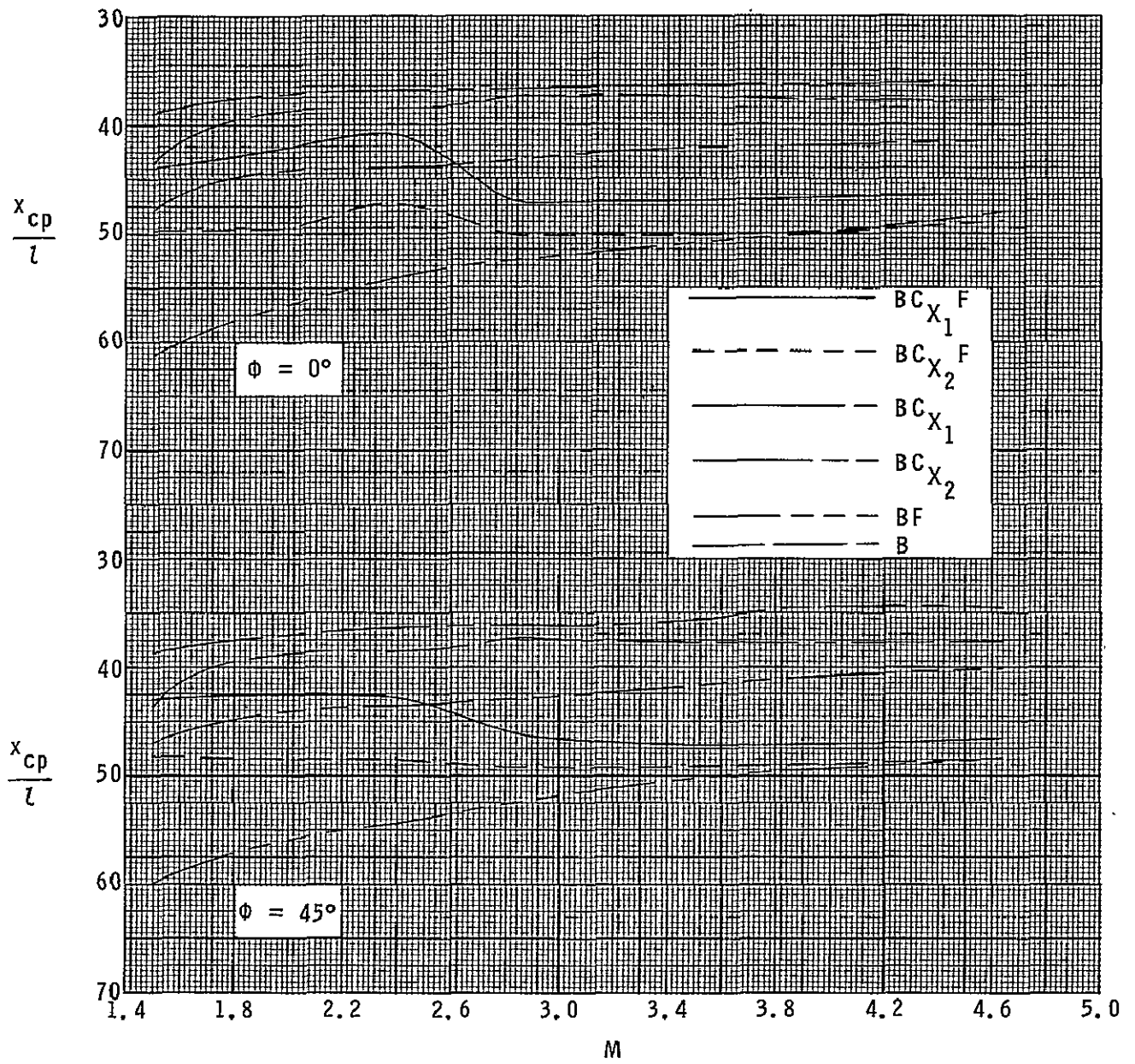
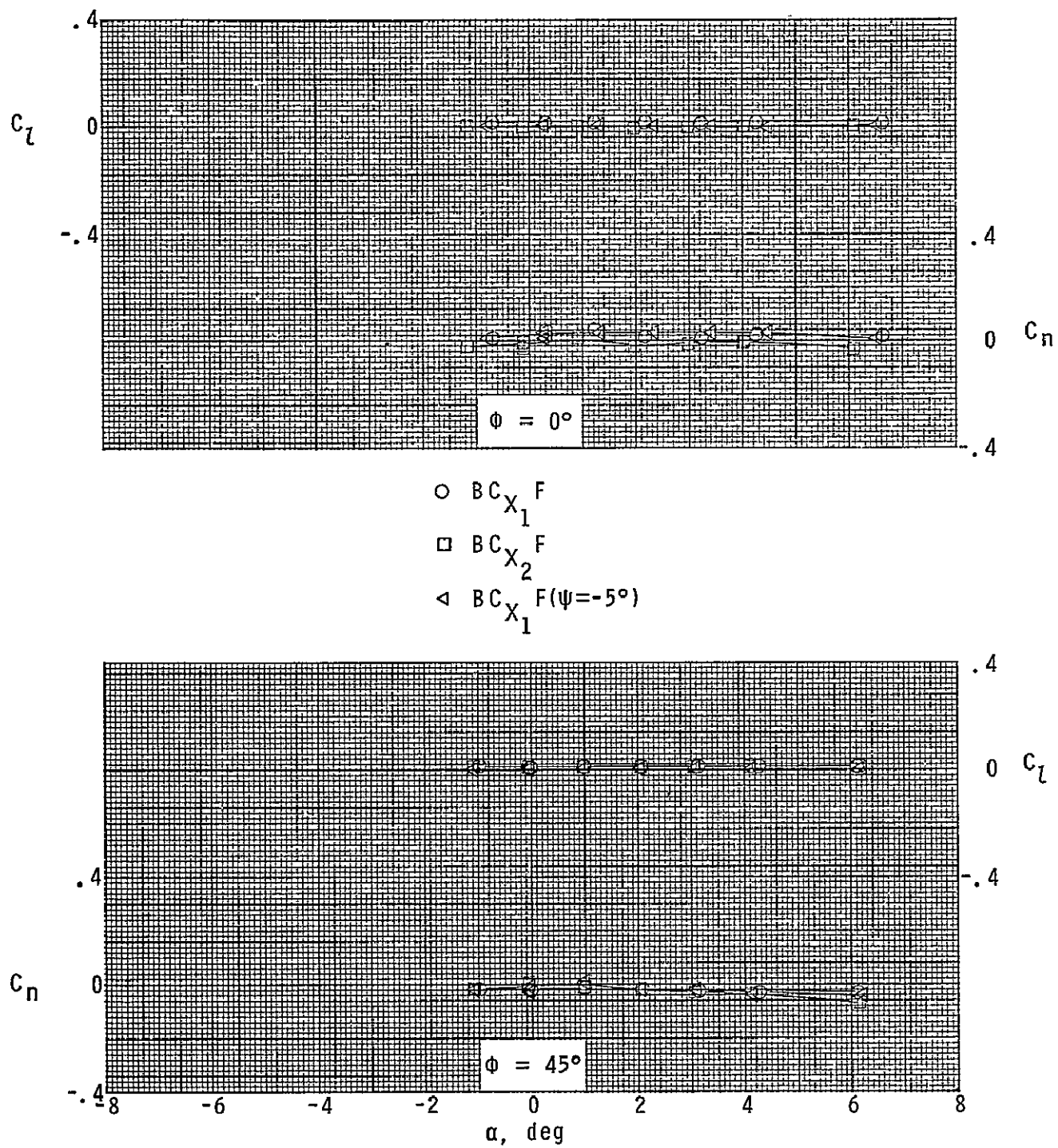
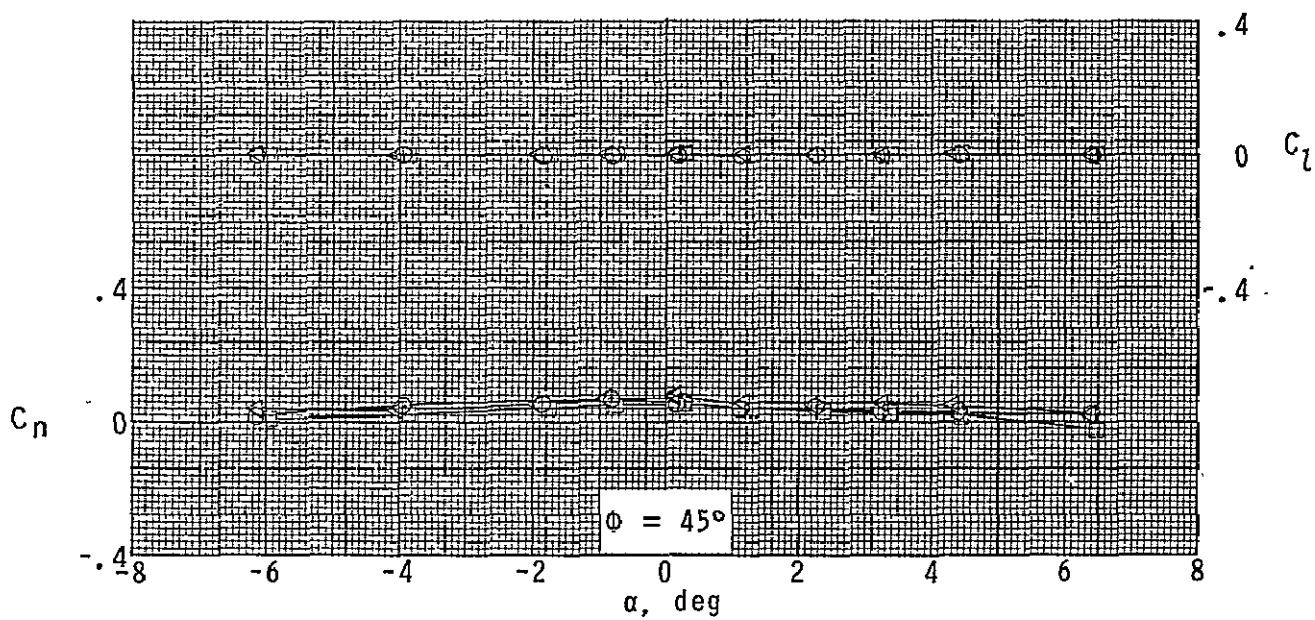
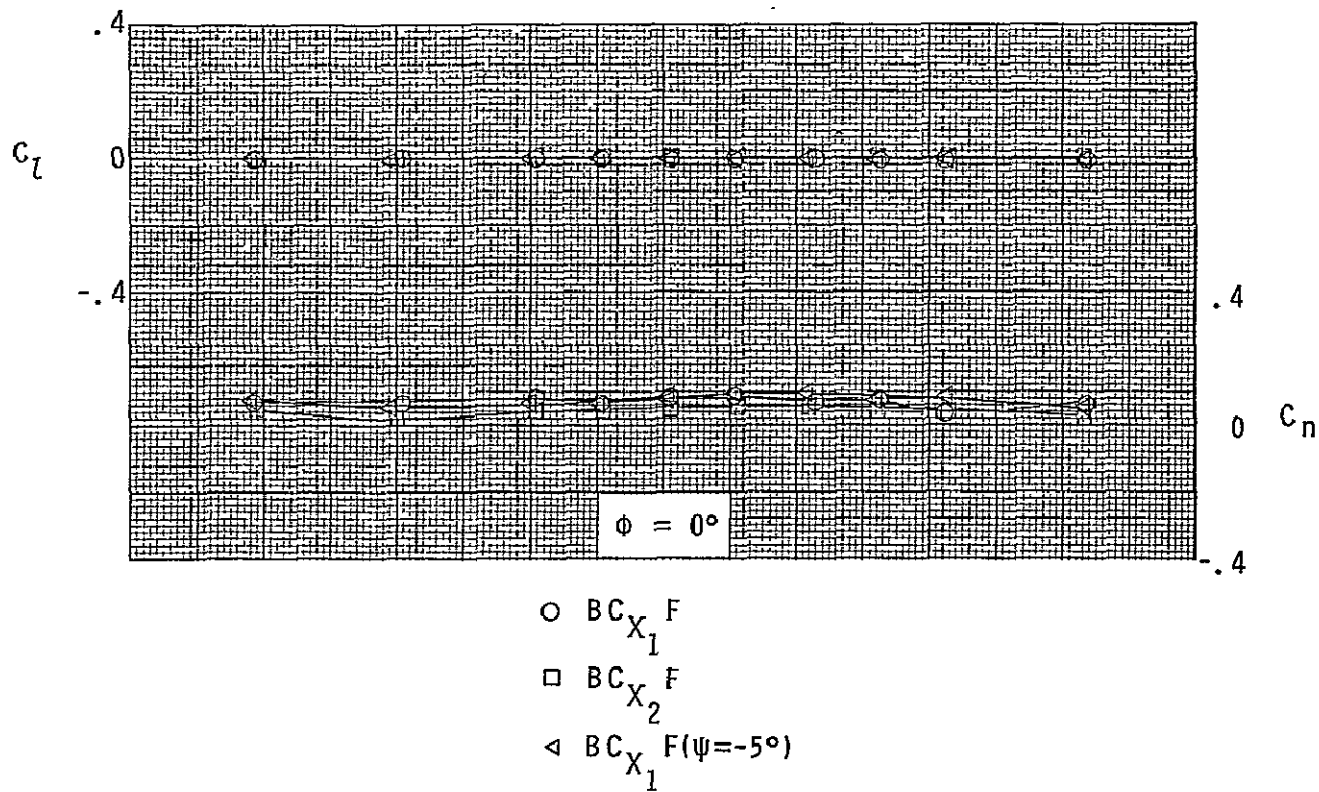


Figure 10.- Variation of center-of-pressure location with Mach number.



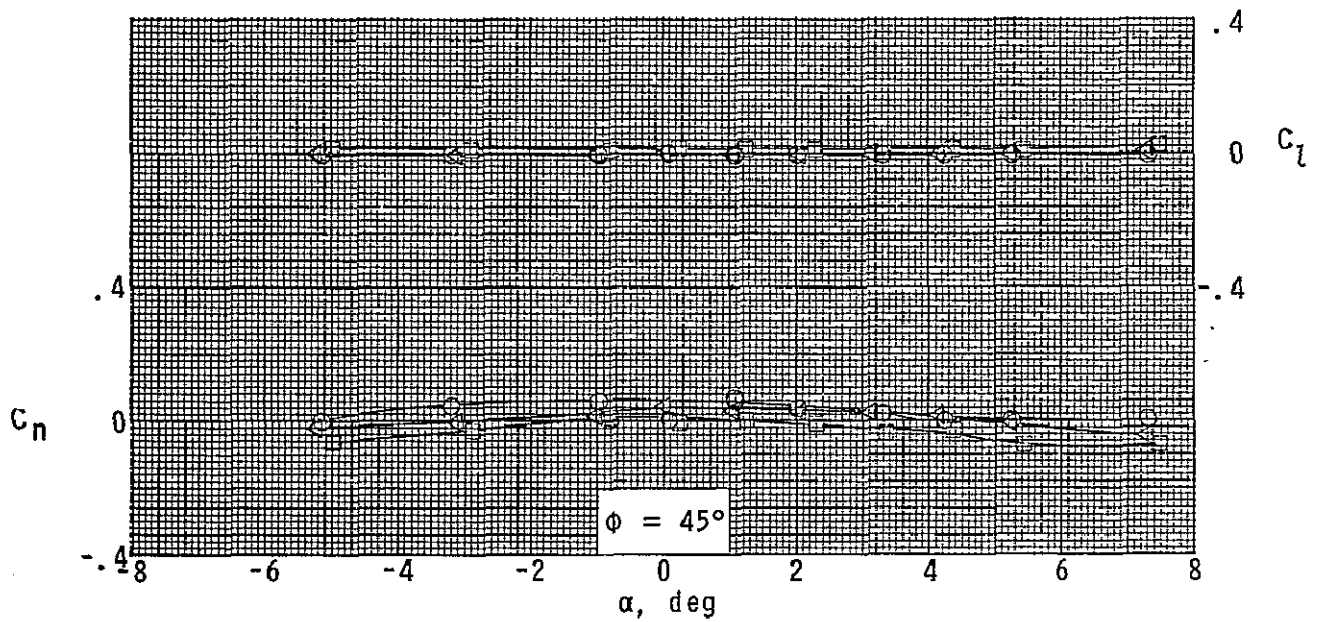
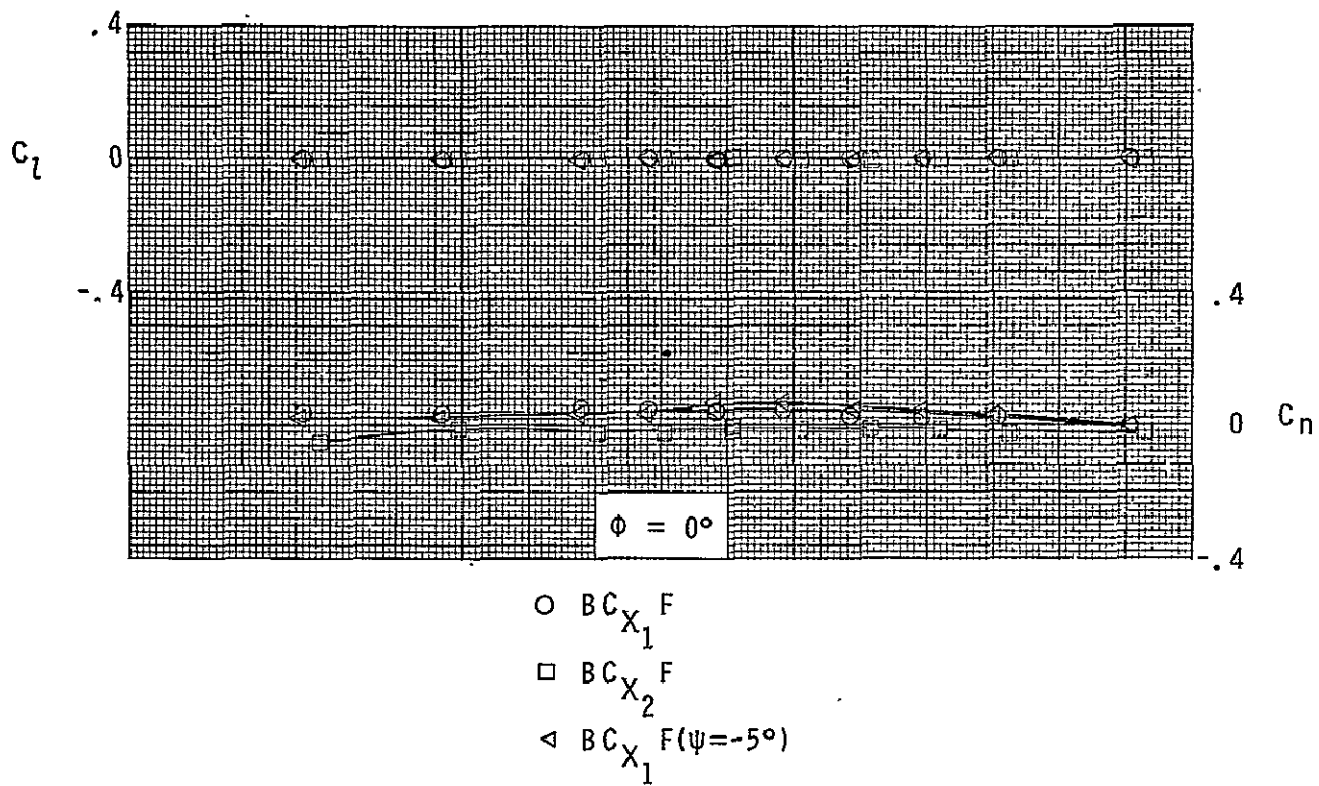
(a) $M = 1.50$.

Figure 11.- Effect of wing position on the lateral characteristics of the complete model.



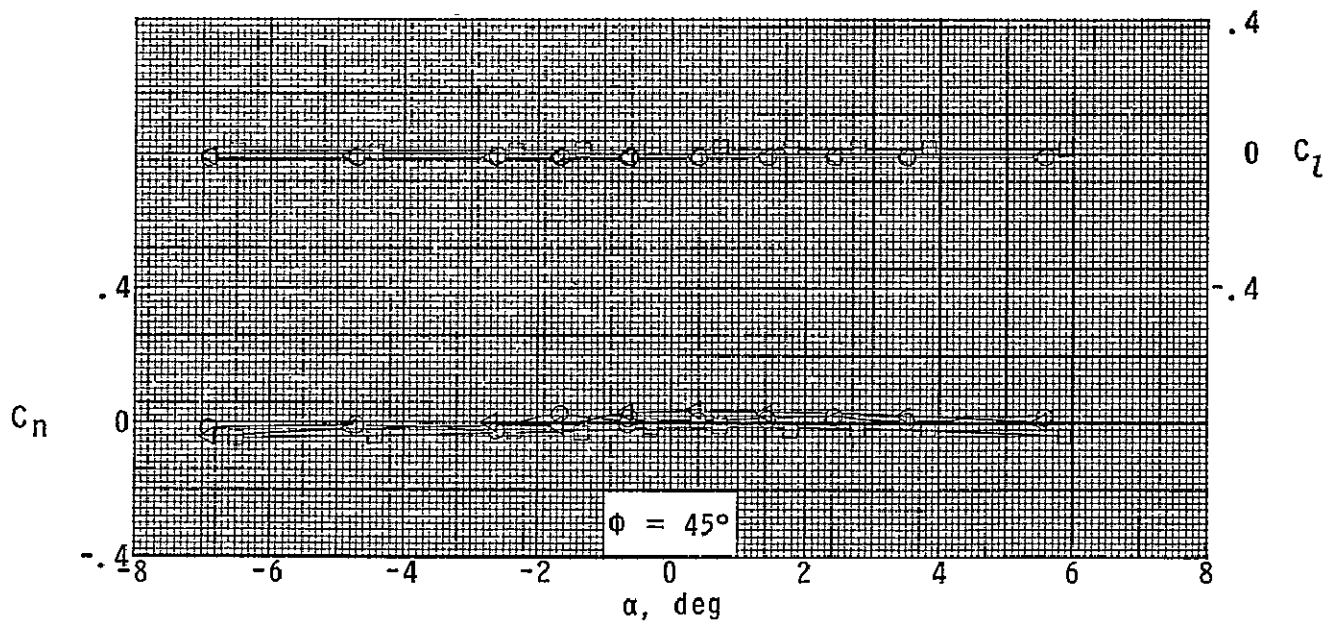
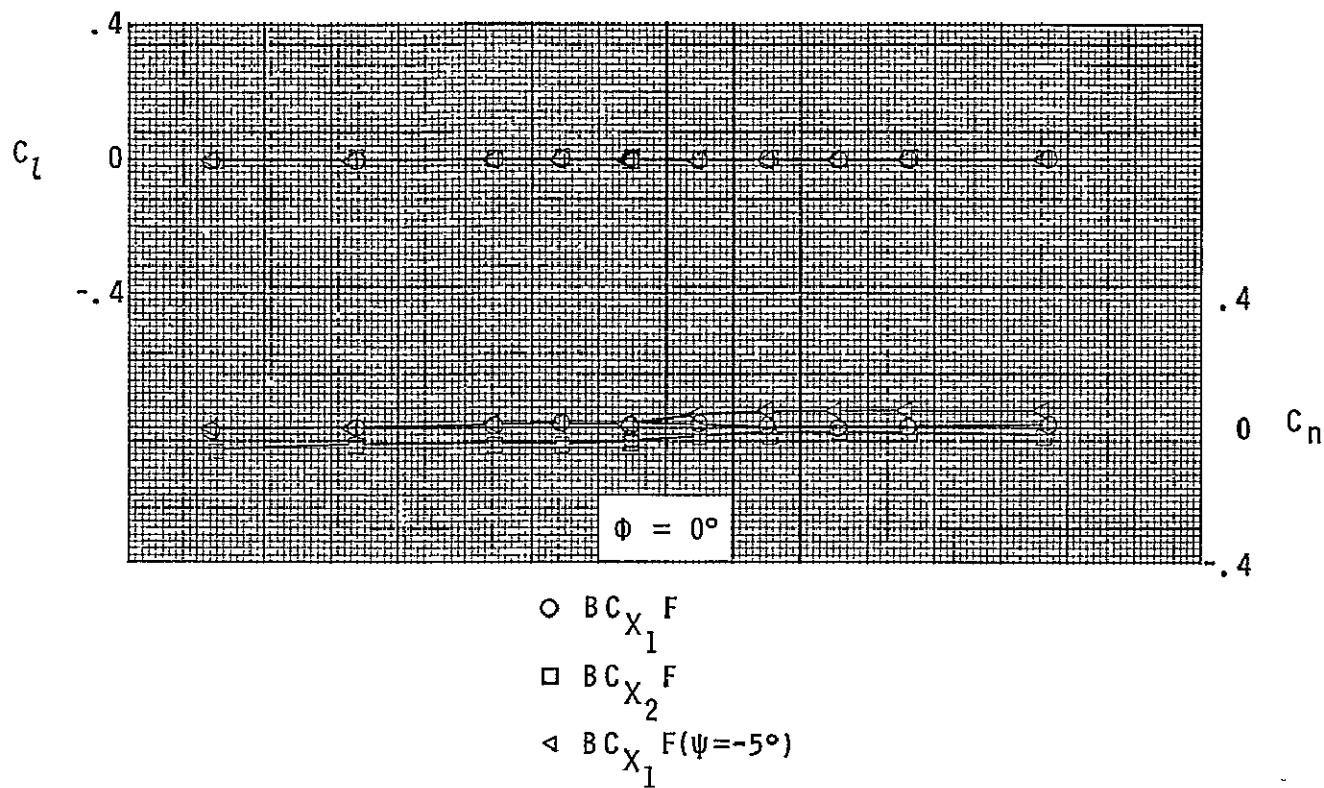
(b) $M = 1.90$.

Figure 11.- Continued.



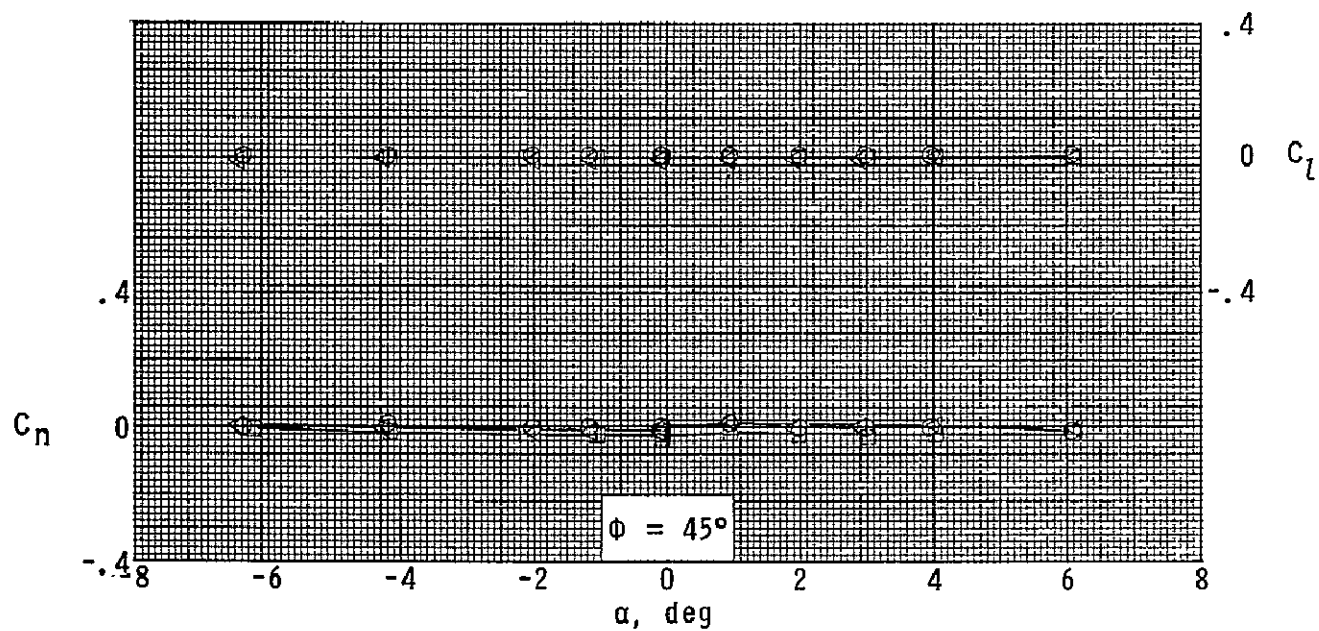
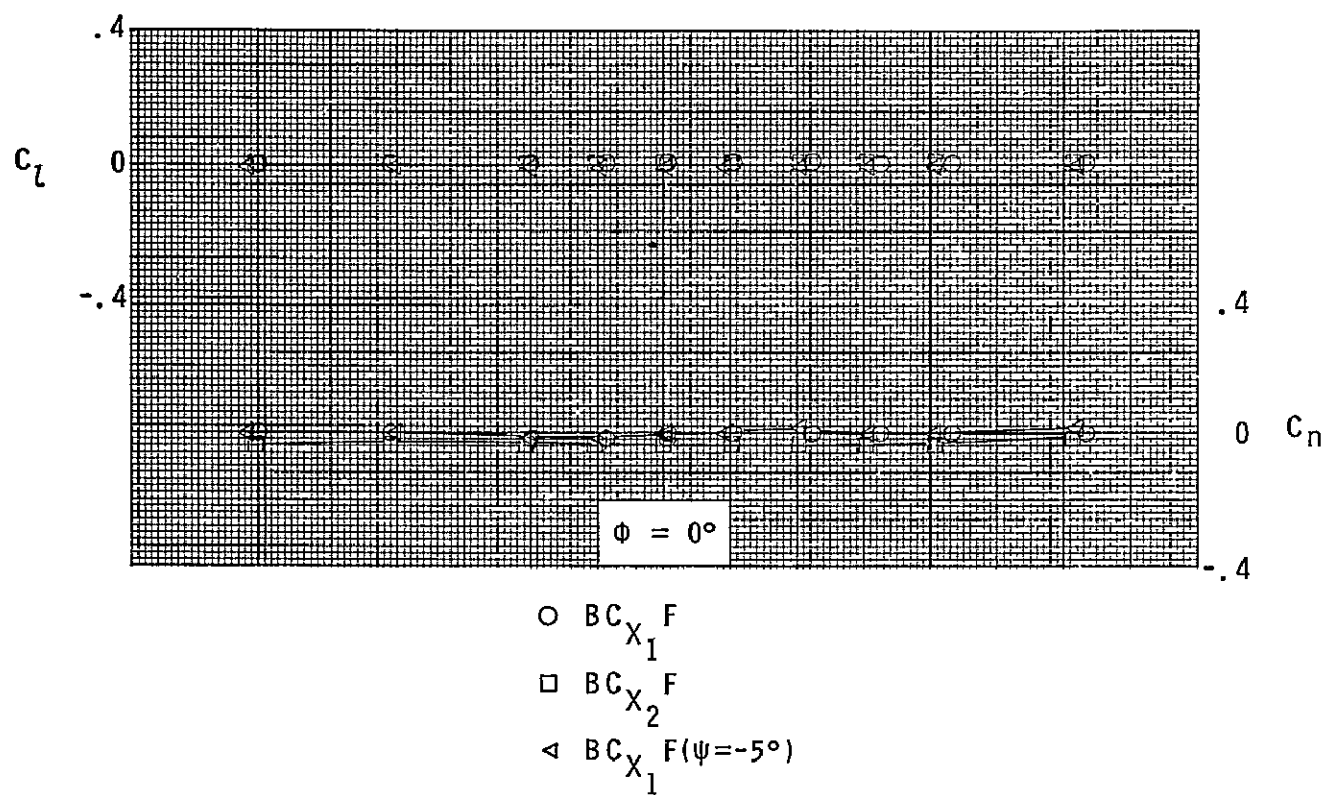
(c) $M = 2.36$.

Figure 11.- Continued.



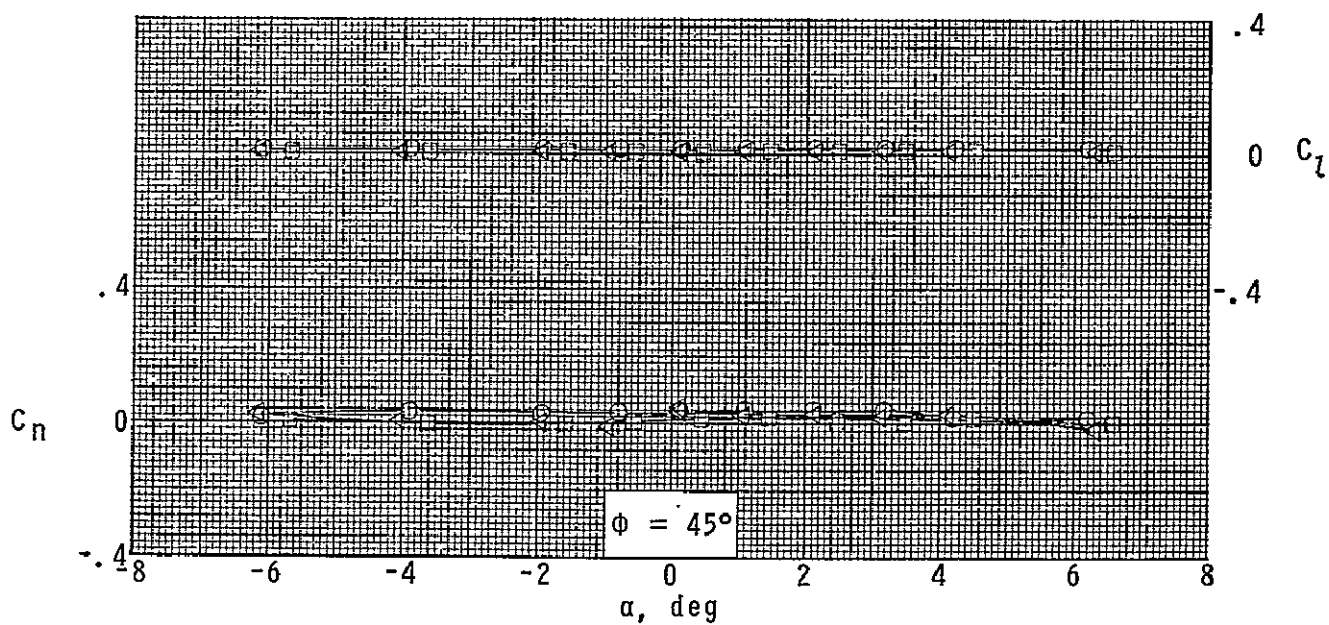
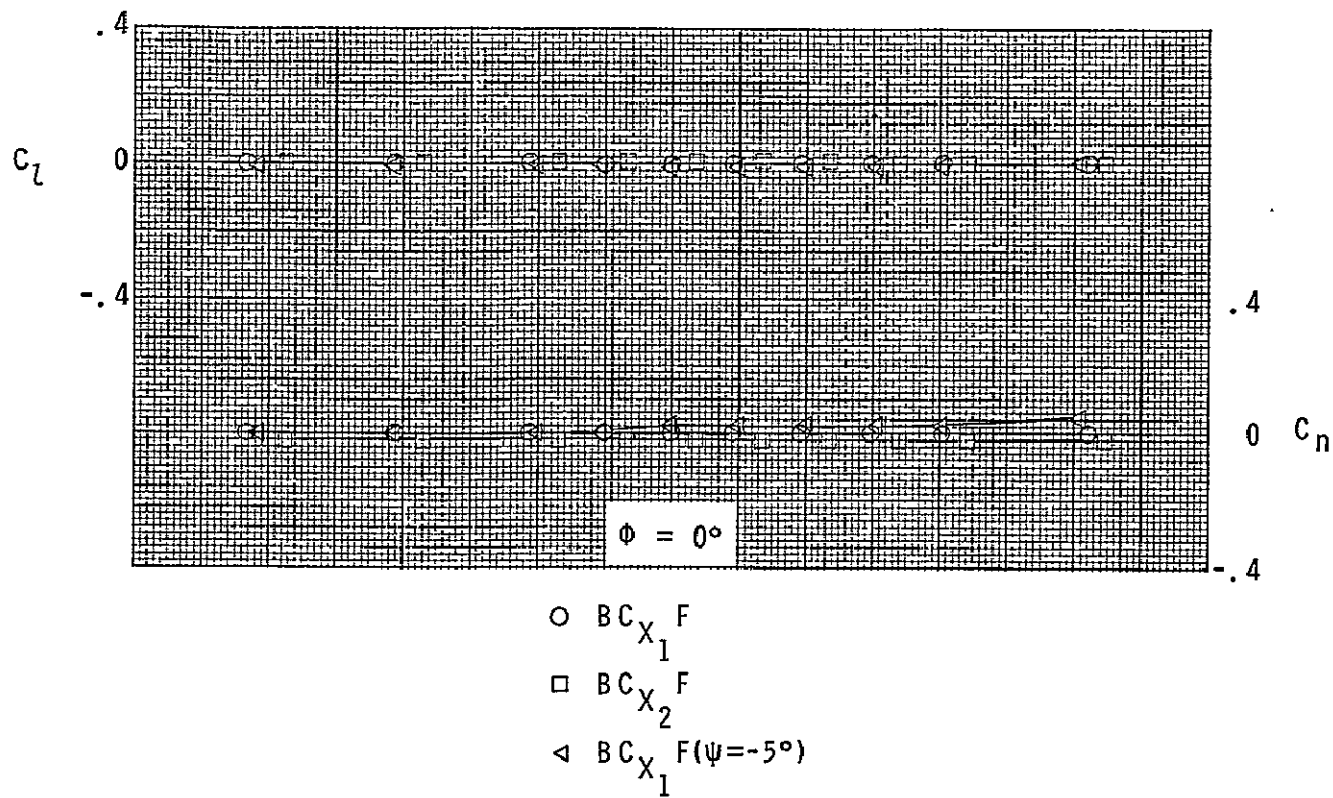
(d) $M = 2.87$.

Figure 11.- Continued.



(e) $M = 3.85$.

Figure 11.- Continued.



(f) $M = 4.64$.

Figure 11.- Concluded.

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